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U. S. Naval Gun Factory, Washington 25, D. C.

NAVAL ORDNANCE LABORATORY MEMORANDUM 9090

26 February 1948

From: TM (A. H. Erickson)
To: NOL Files

SUBJ: 1" Cartridge (Bomb Ejector) Mk 1 Mod 1 - Design-Proof Tests of (Project AM-161).

Abstract: A pre-production lot of 100 subject cartridges was made at NOL and submitted to the Technical Evaluation Department for design evaluation. A Douglas Bomb Ejector was mounted vertically on a specially-designed tower in the White Oak explosives area and shots were made with instrumentation to record pressure, acceleration, firing times, hook-opening times, ejection velocity, probable propeller clearance, etc. Most of the experiments were made with the 2000-lb bomb which represented the greatest load for the cartridge and the ejector. From an operational standpoint (the storage characteristics of the cartridge were not established since no surveillance tests were run on these unsealed samples) the design is found to be acceptable with a maximum firing delay less than one-tenth that of its predecessor, the Aircraft Starter Cartridge. On ejection the average clearance between the 2000-lb bomb and the "propeller tip" circle was about three ft which is 10% to 15% more clearance than that obtained with the starter cartridge.

Foreword: The data and conclusions presented herein are prepared by the Technical Evaluation Department and represent the present opinion of the Naval Ordnance Laboratory.

Ref:
(a) DBE Assembly - Douglas Aircraft Dwg. #5256285.
(b) BuOrd Specification #1126 - Aircraft engine-starter cartridge.
(c) BuOrd uncl ltr EN6-26/S78(Re2e) to NOL dtd 7 Sept 1945 [NOL File EN6-27/F41-6(1-597)].
(d) Drawings on 1" Cartridge - Listed on SK 166557.
(e) NOLM 9282.- Primer Compound XC-9, Properties of.
(f) TSS 4311.
(g) SK 99161.
(h) SK 95023, SK 95024.
(i) SK 84589, SK 84595, SK 95024.
(j) NOL Notebook #0226.

(k) Douglas Aircraft Co. Report #ES-6784.
(l) Douglas Aircraft Co. Dwg. #2252404.
(m) Douglas Aircraft Co. Dwg. #2252414.
(n) Douglas Aircraft Co. Dwg. #2252408.
(o) NOLR 884 - NOL Recording Accelerometer, Type 1A and Type 2A.
(p) NOLM 8860 - Standard (Laboratory) Transportation Vibration Tests and Special Design Vibration Tests as used for NOL Ordnance.
(q) NOL conf ltr to BuOrd dtd 14 May 1947 [NOL File EN6-27/F41-6(1-702)].
(r) NOLM 9206 - Bomb Ejector Cartridge Mk 1 Mod 1, Report of Test of.

Encl: (A) (HW) Tables I through III.
(B) (HW) Plates 1 through 22.

PARAGRAPH OUTLINE

PARAGRAPH OUTLINE contd

INTRODUCTION

1. Modern dive-bombing techniques call for full wing-flap braking while the bomb is being released during an attack. Since the bomb itself is more or less streamlined and has no air brakes of its own, its velocity (relative to that of the plane) will increase and consequently it will "fall" ahead of the plane. Many of the newer bombers have large propellers which must be cleared by the bomb in its forward flight.

2. A combination bomb-rack and displacing gear device, called the Douglas Bomb Ejector [Reference (a)] (Plates 2, 3, 4 and 5), had been developed which, at the instant of release, propels the bomb free and clear of the propeller, even when the plane is in a 90° or vertical dive.

3. The athwartship force is produced when an explosive cartridge is fired against a piston which is mechanically linked to the bomb by a pressure foot. Through another mechanical linkage, the pressure build-up in the firing chamber causes the bomb-rack hooks to open at the time force is applied.

4. This ejector was designed to accommodate the standard aircraft-starter cartridge [Reference (b)] which proved to be unsatisfactory for this particular use because of the existence and variableness of an appreciable firing delay (avg 211 milliseconds). Consequently the Naval Ordnance Laboratory was requested [Reference (c)] to develop a new cartridge for this purpose. This new cartridge is called the 1" Cartridge (Bomb Ejector) Mk 1 Mod 1 (Plate 1). In December 1946, it was submitted to the Technical Evaluation Department for evaluation.

DESCRIPTION OF CARTRIDGE

5. The 1" Cartridge (Bomb Ejector) Mk 1 Mod 1 (which looks like an oversized shotgun shell) is approximately one-in. in diameter and 3.175 in. long [Reference (d)]. The shell case is extruded aluminum and has a brass electrical firing contact in the center of the breech end, in place of the percussion cap usually found in ammunition of this sort. The initiation of the cartridge is accomplished by electric current flowing through a double bridge wire which is embedded in the sensitive XC-9 primer mix [Reference (e)].

6. Starting at the primer end, the powder charge consists of 2.2 gms of FFG Black powder, 2.0 gms of "small" (0"10 x 0"12) smokeless powder, the final compartment containing smokeless powder mixture of 2.4 gms of "medium" (0"25 x 0"25) and 22.0 gms of "large" (".312 x ".312) pellets. A cellulose-acetate disc is placed after the black powder sub-booster and after the "small" smokeless powder booster. A similar disc is used in the muzzle end to retain the main smokeless-powder charge.

PURPOSE OF EXPERIMENTS

7. The purpose [see Reference (f)] of the experiments reported herein was to:

a. determine the effect of normal handling and aircraft vibration on the reliability and performance of this design.

b. determine the effect of temperature on the reliability and performance of this design.

c. determine the firing energy and ignition time.

d. determine the pressure-time relationship in the firing chamber during the firing cycle including the instant of application of firing voltage and the instant of hook opening.

e. obtain acceleration-time curves of the bomb during projection.

f. obtain high-speed motion pictures of the bomb trajectory.

g. compare chamber-fouling with that produced by the Mk 1 Mod 0 cartridge.

8. All of this information was to be obtained using a BT2D-1 Bomb Ejector mounted to simulate a BT2D-1 Dive Bomber in 90° or vertical dive.

PRELIMINARY ACTIONS

9. Obtained Bomb Ejector - A Douglas Bomb Ejector (BT2D-1, serial #8) was obtained from the Bureau of Aeronautics Armament Division for carrying out the above experiments. Since the laboratory had no previous experience with this device it was necessary to study its normal operation and to become familiar with its components so that instrumentation could be applied in obtaining the requested information.

10. Built Bomb Ejector Tower - Since the ejector was to be mounted in a vertical position, it was necessary to design a tower which would withstand the repeated shocks of firing. It was discovered by the Naval Proving Ground at Dahlgren, that when the 2000-lb bomb was ejected, this thrust was sufficient to displace two 12" x 12" wooden uprights set in concrete. Consequently for our use a reinforced-concrete tower (see Reference (g) and Plate 6) 19-ft high was constructed on a 14 cu yd reinforced concrete base which extended to a depth of eight ft below ground level. A 12-in. "I" beam equipped with a pulley was bolted to the top and a gasolene-driven winch was mounted 100 ft in front of the tower to serve as a hoist. Two shorter 12-in. beams were imbedded in the concrete to support the bomb ejector and its load.

11. The tower and ejector mount were designed to simulate closely the BT2D-1 Dive Bomber in a 90° or vertical dive. The measurements used (Plate 10) were obtained from a plane at Patuxent Air Base. Since we wanted to measure the clearance obtained between the bomb trajectory and the circle described by the propeller tips, it was decided that the earth's surface should represent the plane of propeller rotation and the ejector was therefore mounted at the proper height (Plate 10) to establish this.

12. <u>Designed and Constructed Ejector Mount</u> - A mount was designed which would accommodate the ejector stud bolts and which would fit the two 12-in. channels imbedded in the face of the tower. Eight-in. standard steel angles and half-in. steel plate were welded together to form a rectangular hollow box [Reference (h)], whose inside faces were drilled and tapped to fit the bomb ejector. (See Plate 7.)

13. <u>Designed and Built Photographic Grid</u> - In order to facilitate the frame-by-frame study of the proposed motion picture records, a large white back-board was constructed and painted with regularly spaced orthogonal black lines. Each photographic frame would therefore include this black-and-white grid to serve as a cartesian coordinate system in the plotting and study of bomb trajectory.

14. <u>Designed and Built Slip-Stream Simulator</u> - Since our experiments with the bomb ejector were to be static and not dynamic as would be experienced in an actual dive-bomber operation, it was reasoned that some device should be devised to simulate that upward drag force (approximately 500 lbs on the 2000-lb bomb) produced on the bomb by the slip stream. (In the BT2D-1 Type Dive Bomber, the bomb is carried under the fuselage and is always exposed to the slip-stream force.) To supply this upward force (only until the bomb leaves the hooks) we designed the slip-stream simulator whose force link consists of a stout spring, a turn-buckle and a dynamometer, and fastens to the bomb tail with a slide-fork arrangement. [See Reference (i) and Plate 6.]

15. In practice, after the bomb is in place, the fork-end of the slide arm is so placed that the slide bar (fastened to the bomb tail) is between the prongs with the upper (plate) end of the bar resting on the fork. The turn-buckle is then tightened until the upward force applied by the spring is seen to be 500 lbs as indicated by the dynamometer. On ejection, after the bomb has moved a horizontal distance of approximately one in., the slide bar is withdrawn from the fork at which time the upward force is discontinued. This device was used on only three shots because camera studies showed no appreciable change in trajectories when the simulator was not used. Another reason for its being discarded on subsequent shots was that the time consumed in the extra rigging resulted in a firing schedule which was not acceptable to the Bureau of Ordnance.

DIFFICULTIES ENCOUNTERED

16. Premature Hook Opening - On Friday, 31 January 1947, the ejector was bolted to its vertical mount and the 2000-lb bomb was placed in the hooks preparatory to firing the first shot. The first cartridge was inserted, and as the breech was being screwed down, the upper (aft) hooks opened allowing the bomb to rip out the bottom hooks as it fell to the ground [Reference (j)].

17. A visit to the Armament Division of the Bureau of Aeronautics (Mr. Broad, Bldg. W, Room 1W36) uncovered a Douglas Aircraft Company Report [Reference (k)] published in April 1945, in which a similar incident was reported during the design testing of this ejector. It was their experience also that the same hooks were torn out on seating the breech (they were testing an ejector of identical design).

18. To avoid this difficulty, it was recommended in the Douglas report that the pull-rod nuts be loosened until a positive clearance is obtained between them and the retainer plate, while the release and upper sleeves are in the "down" or non-release position. However, a careful study of the bomb ejector by the writer, showed that with this adjustment, the hooks would not open even when the release and upper sleeves were in the retracted or release position.

19. It was therefore concluded that some intermediate adjustment of the pull-rod nuts was necessary. Since the critical governing factor was the movement of the sear-bar and rod during the tightening operation of the breech, a method of detecting the slightest movement of this sear-rod was needed. A simple electrical screw contact was installed near the upper (aft) sear rod so that the slightest movement of this rod would light an indicator lamp, calling for a readjustment of the pull-rod nuts.

20. Details of the Adjusting Operation - With the 2000-lb bomb in place, and with the factory setting of the pull-rod nuts (see Plate 3), the indicator-contact screw was set so that the lamp would signal the beginning of sear-rod movement. The breech is equipped with a ball-ratchet device so the "notch-count" served as a vernier indication of seating proximity when sear-rod movement began. With this initial (factory) setting, the indicator lamp went on when the breech was screwed in 12 notches. Since the breech was far from being seated, the pull-rod nuts were both loosened one turn. With this adjustment, the breech could be advanced to 23 notches but was still not seated. Loosening the nuts again, 28 notches resulted and the final adjustment allowed 37 notches without producing movement of the sear-rod. With this setting, the breech was completely closed and was ready for firing. However, since the pull-rod nuts were now in such a position to prevent

the insertion of the cotter pins (see Plate 4), and since the final adjustment was not known to be stable over a series of shots, the technique of using the indicator lamp was employed on all subsequent shots during the breech-securing operation.

21. Pressure-Foot Ejected with Bomb - On shot no. 6 the piston and foot assembly followed the bomb in flight for a short distance but was saved from damage by the strain-gauge wires which retarded its flight. Examination revealed that the piston head [Reference (l)] had become unscrewed from the piston [Reference (m)]. The piston-head gasket [Reference (n)] was badly deformed and it is probable that the shock of preceding shots had loosened the stake to the piston and allowed the piston-head to unscrew. After this shot, the gasket was re-formed and the firing was resumed. This old gasket was used on two more shots but for shot no. 9 and subsequent firings a new gasket was furnished by the Aviation Ordnance Division of the Naval Gun Factory.

22. Cartridge Extraction Difficult - In every instance we found it difficult to remove the empty shell case from the powder retainer after firing. The extruded aluminum case would swell under firing pressure and temperature and would have to be removed by using a long thin ramrod inserted through a hole in the muzzle-end of the retainer. During the course of the tests two other retainers (Plate 8) were tried in an effort to overcome this trouble but without success. One of these retainers was almost identical to the production model but was coated inside with a thin layer of chrome (retainer B) supposed to prevent adhesion. The other retainer (C) had a chamfered shoulder and a slot milled across the face at right angles to the axis to allow the use of a screw driver as an extractor. When this retainer was used however, considerable gas leakage was observed, indicating that the slot was milled too deeply.

INSTRUMENTATION

23. Firing Energy and Ignition Time - To obtain the minimum firing energy and the true ignition time for the priming mix, the TM-1 method outlined in NOLM 8636 was used. In this method a resistance-time curve for the bridgewire is obtained and the change of slope of this curve indicates the point at which much additional heat is applied to the bridge wire by combustion of the priming mix and therefore represents the true ignition point. By integrating the power-time curve (EIdt) from t equals 0 to t equals ignition value, the actual firing energy is obtained.

The values of E, I and t were measured with the NOL six-trace CRO (Plate 14).

24. Pressure-Time Relation - The best known method for obtaining the pressure-time curves in the explosion chamber calls for the insertion of a plug-type strain-gauge, in which resistance wire is non-inductively wound around a ferrule having one end exposed to the unknown pressure. To use this gauge it would be necessary to drill a half-in. hole through the chamber wall. Due to the relative sliding motion of the piston and its sleeves, no perforation was possible except through the center of the ejector foot. It was concluded that such a hole would materially weaken the foot, so the best alternate was the use of two Baldwin-Southwark SR-4 Type C-7 gauges which were cemented to the inside of the foot (see Plate 5). These two gauges were connected in two arms of a bridge circuit (see Plate 15) whose output was fed to one element of the six-trace oscilloscope.

25. The foot was calibrated in lbs (see Plate 17) so the strain-gauge output gave us the force-time curve during ejection. Since pressure equals force per unit area, (using the area of the piston head) we calculated the pressure at regular time intervals to obtain very satisfactory pressure-time curves.

26. Hook-Opening Time - This measurement is herein defined as that interval from the beginning of pressure rise until the instant at which the hooks begin to open. On the upper (aft) hook of each set, we placed a narrow copper strip which was insulated from the hook by masking tape and was held in place by a stout rubber band. When the hooks were closed, an electrical connection was therefore made between this strip and the lower jaw (see Plate 7). The current flowing through these two contacts produced a deflection on two adjacent traces of the oscilloscope which gave an immediate sharp signal when the hooks began to open.

27. Acceleration-Time Relation - Two types of accelerometers were used (a) NOL Piezo-Electric Accelerometer Pickup, Serial #19, natural frequency 6500 cycles per sec [Reference (c)] and

(b) the Statham or strain-gauge type (Waugh Laboratories Catalog #R-10-240, Serial #194, natural frequency 270 cycles per sec., range ± 10 g).

28. The first acceleration measurements were made with the piezo-electric accelerometer mounted in the 2000-lb bomb (both pickups were mounted at the bomb's center of gravity on a wooden support wedged tightly inside the sand-filled case) to give accelerations along a line perpendicular to the axis of the bomb through the center-of-gravity and in the plane of the C.G. and the bomb lugs. Since this device was of the high-impedence type, it was necessary to use a cathode-follower pre-amplifier to match the circuit impedance. (It is highly desirable to use low impedance cable circuits to minimize mutual inductive reactance which produces spurious signals.)

29. Firing Circuit - To obtain the specified firing potential of 24 volts at the cartridge end of the long firing leads all cartridges were fired by applying 30 volts (from heavy duty storage batteries) to a circuit (Plate 15) containing a total resistance of approximately one ohm (varied with each cartridge and with temperature of firing leads). This reading was taken before each shot and included total circuit resistance with the exception of the batteries whose internal resistance was assumed to be very low even at currents as high as 30 amps. The potential-time curves were recorded by one element of the six-trace oscilloscope connected directly (as near bridgewire as practicable) across the ejector firing plug.

30. The current-time curves were also recorded by one element of the six-trace which measured the IR drop across one leg of the firing cable whose resistance was carefully obtained each time with a wheatstone bridge.

31. The Statham Accelerometer was mounted in the bomb in line with the Piezo-Electric pickup and was connected to the oscillograph as shown in Plate 15. Although this device was of the low-impedance type and was consequently easier to use than the other pickup, it appeared to overshoot the peaks because of a low natural frequency.

32. High-Speed Motion Pictures - Two types of pictures were taken during the tests:

a. 35mm Fastax recording at 2000 pictures per sec, made only on a few of the early shots to observe any irregularities of hook openings, etc.

b. 16mm movies at 64 pictures per sec from which each firing trajectory was plotted (Plate 10).

Since the latter recording included a synchronous timer in the field of view, the horizontal velocity of the bomb after ejection was obtained on a sufficient number of shots to check the values obtained by integration of the acceleration-time curves.

33. <u>Fastax-Six-Trace Automatic Synchronizer</u> - This automatic device (Plates 12 and 13) was developed by TM-1 to accomplish in correct sequence:

a. Six-Trace starting,
b. Six-Trace calibration,
c. Fastax starting,
d. Firing,
e. Fastax stopping,
f. Six-Trace stopping.

The proper timing was obtained with Western Electric stepper switches whose step frequency was accurately controlled by an RC circuit.

CALIBRATION

34. The voltage and current traces of the CRO were automatically calibrated during each shot. As the six-trace film reached normal operating speed, a stepper contact in the synchronizer circuit operated a relay which momentarily connected these two channels to the calibration circuit as shown in Plate 15. While this momentary connection was made, a falling weight was automatically released which quickly removed resistances successively from this circuit to apply a known stair-step signal to each element. This calibration relay dropped out before the stepper firing contact was made.

35. Immediately after each shot, the strain-gauge and accelerometer channels were calibrated manually. In the case of the strain-gauge and Statham circuits, a potential-divider was used to produce a known voltage which was applied at the pickup end of each channel.

36. The piezo-electric accelerometer channel was calibrated by applying a known a-c voltage to the pre-amplifier input thus eliminating the necessity of determining its amplification.

37. The calibration of the piezo-electric pickup and the Statham pickup were obtained from curves furnished by TM-2. The force calibration of the pressure-foot strain gauges was accomplished by TM-3 who furnished the curve shown in Plate 17. This foot calibration was repeated at intervals during the test, and identical curves were obtained attesting the ruggedness of the system.

TYPICAL EXPERIMENTAL PROCEDURE

38. The typical sequence of events for each shot is as follows:

a. Hoist bomb into position, snap shut the ejector hooks after insertion of bomb lugs, release hoist cable and secure the foot against the bomb (contact points of foot against bomb are well lubricated so as to duplicate conditions under which foot was calibrated).

b. Check insulation resistance of piezo-electric cable conductors.

c. Make all cable connections at six-trace CRO and accelerometer pre-amplifier, and check all connections on connector strip at the ejector end.

d. Warm up the six-trace, pre-amplifier, and pulse generator (if Fastax is used).

e. Set up cameras and connect associated cables.

f. Make final accelerometer and strain-gauge connections at the bomb and make visual check for deflections in the six-trace.

g. Check continuity of hook switches by observing six-trace deflections as battery is applied.

h. Insert cartridge and container assembly in the ejector and seat the breech using the indicator-lamp procedure outlined in paragraph 22.

i. Connect firing leads and check continuity of firing circuit with the indicator lamp (Mazda #313).

j. Measure the resistance of firing circuit with wheatstone bridge.

k. Start the synchronous timing motor for camera recording.

l. Fire with automatic synchronizer circuit (Plate 13).

m. Measure horizontal projection distance of bomb from nose imprint in earth.

n. Calibrate strain-gauge and accelerometer channels.

o. Remove cartridge shell and weigh the unburned powder.

p. Develop six-trace records, and study to obtain the times, pressures, accelerations, etc.

q. Develop the movie records to obtain trajectory, velocity and earth-impact angle.

r. From trajectory-plot, measure the propeller tip clearance.

SAMPLE DISTRIBUTION

39. The following table shows the plan of cartridge distribution and indicates conditioning and disposition.

Cart. No.	Storage Temp.	Firing Temp.	Mech. Treatment	Disposition
1-7	-65°F	-65°F	Vibrated	Fired
8	-65°F	ambient	Vibrated	Fired*
9-17	0°F	0°F	Vibrated	Fired
18	0°F	ambient	Vibrated	Fired*
19-20	70°F	70°F	Vibrated	Fired
21-28	160°F	160°F	Vibrated	Fired
29-33	70°F	70°F	Vibrated	Fired
34	70°F	ambient	Vibrated	Fired*
35-36	70°F	70°F	Vibrated	Fired
37-46	-	-	Vibrated	X-ray Insp.
47-62	0°F	0°F	None	Fired
63-64	0°F	ambient	None	Fired*
65-81	70°F	70°F	None	Fired
82 (1/2 Load)	70°F	70°F	None	Fired*
83-86	-	-	Jolted (X3)	Fired*
87-90	-	ambient	Jumbled	Fired*
91-94	ambient	ambient	None	Fired*
95-97	-	-	None	To (WA)
98-100 (3/4 load)	-	ambient	None	Fired

"Fired" means in the bomb ejector with normal instrumentation.

"Fired*" means in the bomb ejector using a Bruceton test to determine the minimum firing current.

"(X3)" means 1750 jolts in each of three positions.

DETAILS OF EXPERIMENTS (What was done)

40. These experiments were conducted in the Explosives Area at White Oak, Maryland, during the period 4 February 1947, to 10 April 1947, by the personnel of the Ammunition and Explosives Subdivision. The instrumentation problems were rather complex and acknowledgement is made for the splendid help and cooperation of TM-2 who served as instrumentation consultants throughout the firings.

41. Vibration - Forty-six cartridges were subjected to the standard transportation vibration schedule [Reference (p)] and each bridge resistance was carefully measured before and after the treatment using the "A C Bridge Limited Current" method. Those numbered 1 to 36 and 41 to 46 were vibrated in a vertical position with the breech end up. Numbers 37 and 38 were in a horizontal position; 39 and 40 were treated vertically with the breech end down.

42. Radiographic Inspection - Ten of the above vibrated samples (37 - 46) were given radiographic inspection (Plate 11) to check for separation, displacement or breakage of components.

43. Temperature Conditioning - In accord with the sample distribution schedule given in paragraph 39, the cartridges were conditioned to the indicated temperature for a period of 24 hrs before firing. It should be noted that our firings took place during the months from February to April and consequently the ambient temperature varied from 20°F to 60°F.

44. Ejector Firing - A total of 87 shots were made with the Douglas Bomb Ejector and tower as described in the introduction (paragraphs 10, 11, 12). Only 69 of these were made with complete instrumentation, the remainder being fired in a "go - no go" Bruceton test to establish the minimum firing current. Most of the cartridges were tested in conjunction with the 2000-lb bomb since this represented the heaviest load requirement for the ejector and cartridge. However a few were fired with the 500-lb and the 1000-lb bomb to establish the trajectory and the propeller clearance.

45. Record Interpretation Methods - Two types of records were obtained for each firing; (a) the six-trace oscillograph negative on 35mm film and (b) the 16mm motion picture record (64 frames per sec). From a projected and enlarged image (ten diameters) of each oscillograph record, an overlay was carefully made, from which the time and amplitude values were obtained on each trace. An earlier method of obtaining the values directly from the film was discontinued because of the excessive time required. This direct reading was obtained with a microscope adapted for two-way vernier control and the record was studied against a ruled optical grating made especially for this purpose.

46. The bomb trajectory was plotted from 20 diameter projections of the 16mm motion-picture records. The film was placed in an enlarger and the bomb path was plotted from successive frame projections using the cartesian coordinate system described in paragraph 13. Using actual measurements obtained from a BT2D-1 Dive Bomber, we were able to include in each trajectory plot, the nearest point of propeller rotation and thereby to measure the minimum clearance between the propeller and bomb trajectory. A sample drawing showing how the minimum clearance value was obtained, is included as Plate 10. (It should be noted that clearances for the type AD-1 airplane are within one in. of those required by BT2D-1.)

RESULTS

47. Vibration - Out of the 46 given this transportation test, two of the cartridges experienced complete bridgewire failure as shown by resistance measurements. The "Before and After" measurements as given in Table I show that the resistances increased 0.01 ohms on an average as a direct result of vibration. This was possibly caused by a slight elongation (and consequent reduction in cross section) of the bridgewires due to axial movement of the firing contact with respect to the case. A visual examination showed this contact to be loose in several instances so that it could be displaced inward quite easily with a pencil point. The resistance of cartridge no. 39 was almost doubled as a direct result of vibration indicating clearly that one bridgewire was broken.

48. A statistical study was made to ascertain the effect of vibration on the horizontal displacement of the 2000-lb bomb. The results indicated that the difference in ranges between the vibrated and non-vibrated samples was not significant at the 5% level. (That is, it was found that once in 20 times, a difference as great or greater might occur by chance alone.) Another study was made to discover the significant difference between the vibrated and non-vibrated cartridges as regards their "Peak pressure times" (beginning of pressure rise to the instant of peak chamber pressure). Since both vibrated and non-vibrated samples were tested only at 70°F and 0°F, the study was limited to these two temperatures. However, no significant difference was found at the 5% level.

49. Radiographic Inspection - Out of the ten vibrated cartridges examined, three showed clearly that the entire primer assembly (contact, bridgewires and primer mix) was displaced inward (see Plate 11). No evidence of broken powder grains or serious displacement of separators was discovered.

50. Temperature - Although we were not able to measure any appreciable effect of powder temperature (including bridge) on the ignition time, it is shown in paragraph 54 that the

temperature of the bridgewire enters as a logarithm in the second term of the equation there developed. Since the temperature coefficient of Pt-Ir resistance is very small and since the term is logarithmic, it would be difficult to measure the effect over the ranges used in this test. However the powder temperature produced decided variations in the pressure-time curves and is discussed in the reporting of the pressure-time data.

51. Ejector Firing - Minimum Clearance of Propeller From the trajectory plots (see Plate 10) of the 2000-lb bomb, the measured average minimum clearance between the bomb and the propeller tip (51 shots) was 2.93 ft with a maximum of 4.03 ft and a minimum of 2.14 ft (σ = 0.542 ft). These figures do not include lesser clearances obtained in four instances; three shots made with 3/4 powder load and one shot made with a defective powder retainer which allowed considerable gas leakage thereby developing a reduced chamber pressure. As shown in Table 2, when used with the smaller bombs, the Cartridge Mk 1 produced much greater propeller clearance. Because of the absence of slip-stream forces, (after release) the bomb always assumed an angle with the vertical after ejection, usually increasing to 15 or 20 degrees on impact with the earth (the bomb rotating about the nose, the tail attaining a higher linear velocity than the nose). Because of this fact, our results were somewhat pessimistic since this slight rotation caused the bomb-nose trajectory to approach the propeller tip with slightly less clearance than would be expected in practice. The horizontal range of the 2000-lb bomb (bottom measurement of plate 10) averaged 6.26 ft for 57 shots with a standard deviation of 0.601 ft.

52. Ignition Time - Since we know the physical composition and dimensions of the parallel bridgewires, it is possible to calculate the ignition time, defined as the time from the application of current until the wire reaches a temperature of 180°C which is the ignition temperature for the XC-9 mix [Reference (e)]. To make this calculation it is necessary to ignore unmeasureable heat losses which we know to be present and it might be concluded that such a calculation is entirely academic. However the ignition time thus calculated will serve as a guide and we will expect the measured time to be much greater because of the known energy losses. The following calculation is offered as an interesting sidelight.

53. The bridgewire is Pt-Ir alloy (90-10) with a diameter of 0.0020 ± .0005". From the detailed drawings the estimated effective length of each wire is 0.10 in. Since the resistivity of Pt-Ir (90-10) is 24 microhms-cms we can calculate the resistance:

$$R_o = 24 \times 10^{-6} \frac{(0.1 \times 2.54)}{\pi\ (.001)^2\ (2.54)^2}$$

$$R_o = 0.301 \text{ ohms per branch}$$

54. If we assume that the bridgewire furnishes no heat to the explosives or to its supports, and assuming that no solder is present to increase the diameter of the wire, then we can say that all the electrical energy is used to raise the temperature of the wire thus:

$$J\ s\ m \frac{d\theta}{dt} = I^2 R_o (1 + a\theta)$$

where J is the conversion factor from calories to Joules

s is the specific heat of Pt-Ir (90-10) in calories/gm

m is the mass of the bridge segment

$\frac{d\theta}{dt}$ is the rate of change of temperature with time

a is the temperature coefficient of resistances of Pt-Ir.

Then separating the variables and supplying integrating factors:

$$dt = \frac{a}{a} \frac{J\ s\ m\ d\theta}{I^2 R_o\ (1 + a\theta)}$$

and upon integration:

$$t = \frac{J\ s\ m}{I^2 R_o\ a} \log\ (1 + a\theta) + \text{Constant}$$

where the constant is zero when θ is measured from ambient (since $\theta = 0$ when $t = 0$). Substituting numerical values;

$$t = \frac{\overset{J}{(4.18)}\overset{s}{(.03232)}\overset{m}{(.000111)}}{\underset{I}{(1/2 \times 30)^2}\underset{R_o}{(.301)}\underset{a}{(.0012)}} \log_e(1 + \overset{a}{.0012} \times \overset{\theta}{155})$$

$$t = .0000315 \text{ sec or } 0.0315 \text{ ms}$$

55. Because of the conflicting requirements of fast and slow film speeds previously mentioned, it seemed wise to measure the ignition time on only a small number of shots and to concentrate on the pressure-time information. The average

ignition-time value obtained from several reliable shots was 0.45 ms. This value is considerably greater than the one just calculated, showing that only a small amount of the electrical energy is used to heat the bridgewire itself, the remainder being used up in heating the supports, solder and explosive. As shown in Plate 22, the E/I value was directly measured and plotted against time. The ignition time was taken as the time along this curve at which a discontinuity occurred, indicating an abrupt change of resistance caused by the release of heat from the XC-9 mix.

56. Minimum Firing Energy - By integrating the power (EI) time curve from t=0 to t=i (ignition time), we obtain the average minimum firing energy.

$$\text{mfe} = \int_o^i EI\,dt$$

The average value thus calculated was 53.3 millijoules or 533,000 ergs which is much higher than the comparable figure for electric detonators and therefore has a higher degree of electrical safety.

57. Minimum Firing Current - Although this measurement was not contemplated originally, it was discovered that in practice the airplane pilot would test the circuit continuity by connecting a Mazda Type 313 lamp in series with the bridgewire and the battery. The cold resistance of this lamp is only 16 ohms and since the cartridge resistance is very small the resulting current would be approximately 1.85 amperes. This showed the necessity of (1) recommending that additional resistance be inserted in the circuit, and (2) determining the minimum firing current of the cartridge. A Bruceton test was conducted to determine the 50% firing current value. The complete Bruceton diagram for the 18 previously un-pulsed cartridges is as follows:

o = no fire
x = fire
The values given are in amperes.

58. Although the number of samples is small, it is evident from the diagram that the 50% firing current is approximately 1.5 amperes. We can only estimate from the limited data that the standard deviation does not exceed 0.4 amperes. Based on this outside sigma value, the minimum

firing current (the current at which one cartridge in 1000 will be expected to fire) is 260 milliamperes. Since it has been recommended that a series resistor of 120 ohms be inserted in the firing circuit, we can calculate that the resulting "cold" current would be 220 ma and therefore the probability of a cartridge's being fired at this value would be somewhat less than one in a thousand.

59. Peak Acceleration - In Plate 19 the detailed summary of both measured and calculated values of peak acceleration for the 2000-lb bomb (including standard deviations) are given. The mean for all measured values is 6.71 g's and the mean of the values calculated from the pressure-time curves is 4.73 g's. The two means are not expected to agree since the measured value comes from an accelerometer inside the bomb, while the calculated value contains such variations as flexing of the bomb case by the pressure foot and errors in translation.

60. Ejection Velocity - The bomb velocity was obtained in three different ways;

a. From the high-speed movie records
b. By integration of the acceleration-time curves
c. By substituting the horizontal range values in the expression:

$$V = (R - .33)\sqrt{\frac{g}{2h}}$$

where
- V = average velocity of bomb
- R = measured horizontal range (Plate 18)
- $.33$ = length of ejector foot extension
- g = acceleration of gravity
- h = height of bomb from earth (7.458 ft)

All three methods were used on several shots and the results agreed within 5%. However, it was found that the latter method was most sensitive to small changes in velocity and was therefore used to obtain the mean ejection velocity and its standard deviation. The mean (57 shots with 2000-lb bomb) was found to be 8.7 ft per sec with standard deviation of 0.87 ft per sec.

61. Pressure-Time Data - The average maximum peak pressure produced in the powder chamber (2000-lb bomb) was 3840 psi and the highest peak pressure recorded was 5460 psi (see Plate 18). In Plate 20 is to be found four superimposed pressure-time curves, each of which is a composite representing one of the four powder temperatures used in the series of firings. As can be seen in this plate, the total area under each of these curves is practically constant which indicates that the effect of temperature is to vary the rate at which energy is released from the powder. From our data we derived the following empirical expression of the straight line form, $y = mx + b$;

$$y = 45.54 - 0.073\ X$$

where "y" is the time in milliseconds required to build up peak pressure, and "X" is the powder temperature in degrees Fahrenheit. This curve, which fits our results reasonably well, shows that the colder shots require a longer time to build up a peak pressure in the chamber as is to be expected from this particular chemical reaction. Theoretically each pellet of powder must reach a minimum burning temperature before it can be ignited, therefore the increased delay in reaching peak pressure at the lower powder temperatures, is accounted for by the increased time required to get the pellet up to burning temperature. Another theory explains the delay by suggesting the presence of some low-order burning at the lower temperatures, resulting in some secondary gaseous products which in turn are burned. However, we found that the effect of powder temperature variation on the bomb range and propeller clearance was not significant at the 5% level. (Temperatures varied from -65°F to +160°F.)

62. Pressure-time data was not obtained on all shots as requested because of contradictory requirements. To obtain satisfactory curves, the oscillograph film speed had to be sufficiently low for the pressure trace to assume the appearance of a half-sine wave. When the film was run at this slower speed, the current and voltage traces were not sufficiently resolved to allow the plotting of current and voltage time values. Consequently part of the records were taken each way so as to obtain both types of measurements.

63. <u>Hook Opening Data</u> - The pressure at which the hooks opened ranged from 130 psi up to 2690 psi with a standard deviation of 540 psi and an average value of 1000 psi. These values were quite erratic and seemed to have little relation to the size of the bomb. However, they appeared to increase with the number of shots, and very likely this critical pressure is some function of the amount of sludge which accumulates on the interior moving parts of the ejector. The hook-opening times (defined as time from the beginning of pressure-rise to hook opening) ranged from 0.2 ms to 6.0 ms with an average value of 3.71 ms. Perhaps a more realistic definition of hook-opening times should be the interval from current application to hook-opening. These values, which are recorded in Plate 18, were erratic with a maximum of 87.4 ms and a mean of 9.3 ms. In the last two columns of Plate 19 (items 1 and 2) are given the means and standard deviations of two separate time measurements taken from the records. The sum of these two values is the overall time given above, and as can be seen from the large standard deviation, item 1 accounts for all of the erratic times. The abnormally high values were usually caused by a poor electrical connection and a resulting low current through the bridge. However, it should be pointed out that even the maximum value of 87.4 ms does not

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at which the hooks opened increases somewhat with the number of shots indicating a gradual "gumming up" of the release sleeve with respect to the lower sleeve.

67. Powder Temperature - From the results obtained it can be concluded that the higher powder temperatures cause the peak chamber pressure to be reached more quickly but it is seen that the amount of energy released from the powder during the firing cycle is approximately the same for the temperature observed. However, it must be pointed out that only eight shots were made at the 160°F value and only seven at the -65°F value. Although no failures were observed, the reliability of the cartridges was not well established at these extreme temperatures because of the small number fired. No significant effect of the wide ambient temperature range (20°F to 60°F) on the operation of the ejector or the resulting data was noted. The operation of the ejector at -65° was not attempted, however aside from the slight possibility of the freezing of condensate on or between the moving parts, there appears to be no reason to suspect its failure to operate at this service temperature.

68. Peak Firing Chamber Pressure - The Cartridge Mk 1 has a powder load comparable to that of the Aircraft Starter Cartridge size "D" which was used in extensive ejector tests by the Douglas Aircraft Company. According to their report [Reference (k)] the mean peak firing chamber pressure experienced with this comparable cartridge was 5150 psi with a maximum observed peak of 6270 psi. Since our mean peak pressure was only 3840 psi and our maximum peak was only 5460 psi, it is evident that some improvement in this direction has been made.

69. Peak Acceleration - Since the maximum value of acceleration of the bomb was observed to be less than 12 g's it is reasonable to assume that no damage or unsafety of the bomb fuzes is to be expected. Although the acceleration will be higher on the smaller bombs, it is not anticipated that it will be sufficient to affect the bomb load or its components.

70. Surveillance - The cartridges we tested were not well sealed at either end, hence a surveillance test was not run because the results would have been inconclusive regarding production lots. It is known that the surveillance stability of XC-9 mix is rather poor and that moisture causes rapid deterioration of the compound. It is therefore recommended that the Cartridges Mk 1 be packed and stored in hermetically sealed containers.

71. Loose Firing Contact - As pointed out in paragraph 47, in many instances the firing contact of the cartridge was sufficiently loose to allow axial movement when slight pressure

was applied. Although some small movement of this part is likely to result from the breech firing-contact pressure during the tightening operation, no previous displacement of the cartridge center firing-contact should have occurred. If such displacement occurs, one or both bridgewires might break, or a poor connection with the breech firing pin might be expected. It is therefore recommended that in future production lots of this cartridge, the center contact be more tightly secured.

72. Improved Continuity Test Recommended - Although the plane pilot has a safety factor of approximately ten to one when he uses the #313 Mazda Lamp to check the bridge continuity, the resulting current is about 100 ma. It is considered that this much current flowing through any bridgewire embedded in a sensitive primer mix is liable to produce sufficient localized heat (because of differential effects) to initiate the mix. It is recognized that statistically the chances are small and it should be determined by the operating personnel whether such chances are acceptable and what the results of a premature ejection would be. It appears to the writer that the situation is similar to that of measuring the resistance of a detonator with an ordinary ohmmeter. Usually nothing is expected to happen, but it is not an acceptable practice because detonators have been initiated in this manner. Perhaps some device similar to the ordinary silver-chloride cell cap-tester could be used instead of a light bulb.

73. Cartridge Retainer "C" Recommended - As explained in paragraph 22, two new types of cartridge retainers were used in an effort to overcome the difficulty of removing the cartridge after firing. The last one tried was retainer "C" (Plate 8) and although extraction was somewhat facilitated (since a screw driver could be inserted in the slot), the face slot was milled clear through the outer container lip. Because of this fact the lip could not form a good gas seal and allowed some blow-back. It is recommended that retainer "C" be used, provided that the depth of this slot be reduced to allow a better gas seal.

74. Unburned Powder - In 26 cases, some unburned powder remained in the cartridge retainer after firing (Table 3). Although the amounts (1.34 gms avg) were small in most cases, on two shots with the 500-lb bomb, the unburned residue was 9.56 gms and 8.81 gms which is about 34% of the total load. This is proper evidence of (1) poor ignition or (2) overcharge. In any case the bomb's clearance of the propellers was not appreciably affected so no concrete evidence exists to warrant an improvement in this direction. Chamber fouling was not found to be excessive and was similar to that reported in Reference (r).

75. Test Recommended for Douglas Bomb Ejector - Because of our experience of tearing out the forward hooks of the ejector on tightening the breech, it is reasonable to assume a possible unsafe condition when the plane is carrying the 2000-lb bomb. Consequently the following test is recommended;

a. Construct a mount for the ejector so that the assembly (including a 2000-lb bomb) can be shifted mechanically from a horizontal to a vertical position.

b. With the ejector and the bomb hanging in the horizontal position, and with the factory setting of the pull-rod nuts, screw in the breech (the powder retainer and cartridge should be in place).

c. Shift the whole assembly slowly with rough, jerking motions until the bomb and ejector are in a vertical position. It is felt that such a test might disclose a hidden tendency for the hooks to open prematurely.

76. Strengthen Piston Head Stake - As indicated in paragraph 21, under certain conditions the foot and piston assembly of the ejector can be ejected with the bomb. Our investigation showed that at the time of foot adjustment to the bomb, the compression rings in the piston can bind with a simultaneous binding of the piston, and if the stake becomes broken this binding can cause the piston-head to unscrew. Therefore, it is highly recommended that the stake between the piston and the piston-head be strengthened to prevent its being loosened under firing shocks and the consequent relative motion of these two parts from binding torques.

77. Hooks Fail to Open to Locking Position- About 60% of the time, at least one side of one of the ejector hooks did not open completely to the locking position on firing. Sometimes a hook would open its jaws only enough for the bomb lug to clear. This condition could conceivably cause the bomb to tumble or otherwise affect the trajectory and keep it from clearing the propellers. The difficulty seems to be that the helical-twist springs which open the hooks are not strong enough to open the jaws fully as the sear-bar is withdrawn. It is recommended that the design of the ejector be improved to overcome this tendency.

78. Suggestions to Improve Future Tests - The following recommendations are made;

a. Place the photographic grid very close to the trajectory plane so as to minimize parallax in photography.

b. Either keep the number of variables to an absolute minimum or plan to make 500 shots. We varied the temperature, vibrated and non-vibrated samples, the type of cartridge retainer, size of bombs, and the amount of powder load (the latter in only a few instances). (The use of factorial design is applicable here.)

With this number of variables and the relatively few shots under any given set of conditions it was almost impossible to determine the effect of powder temperature on the propeller clearance, etc.

c. Place all instruments closer to the ejector so that short cables can be used, thus minimizing the mutually inductive effects of long parallel circuits.

d. Set up better darkroom facilities on the spot.

e. Spread the samples more evenly over the temperature range and fire some non-vibrated and vibrated cartridges at each temperature.

f. Clean the ejector after each five shots. This would necessitate having at least two ejectors on hand so that one could be cleaned when the other was in service. This frequence of cleaning is not necessary for service use, but is desirable for test purposes so that the variations can be held to a minimum.

g. If a future test appears to require a similar amount of data, plan to keep two people busy full time for a three-months period studying and analyzing the data.

h. Improve the accuracy of range measurement on the ground by welding a small "tit" on the bomb which will make a distinctive mark in the soft earth.

i. Try to eliminate contradictory requirements such as measuring the firing energy and ignition time on the same shots where pressure-time curves are wanted. The firing energy measurement requires a high film speed to resolve the rapid variations in voltage and current, while the pressure-time curves must be recorded at much lower film speeds to produce a usable trace.

A. H. Erickson

AHE/jb

DOUGLAS BOMB EJECTOR CARTRIDGE MK 1 MOD 1
ELECTRICAL RESISTANCE BEFORE AND AFTER VIBRATION

Cart. No.	Resistance in Ohms		Cart. No.	Resistance in Ohms	
	Before Vibration	After Vibration		Before Vibration	After Vibration
1	0.11	0.16	26	0.15	0.15
2	.11	.17	27	.15	.14
3	.12	.13	28	.14	.14
4	.13	.14	29	.15	.17
5	.12	.12	30	.13	.15
6	.13	.15	31	.15	.14
7	.11	.16	32	.14	.14
8	.14	.17	33	.17	.18
9	.15	.16	34	.15	.15
10	.14	.16	35	.14	.15
11	.14	.14	36	.15	.14
12	.13	.15	41	.13	.15
13	.14	.16	42	.14	.15
14	.13	.14	43	.15	.14
15	.14	.14	44	.14	.16
16	.14	.13	45	.15	.13
17	.14	.15	46	.15	.12
18	.13	.15			
19	.14	.14	37	.14	.20
20	.16	.17	38	.15	∞
21	.13	.13			
22	.13	.14	39	.15	.29
23	.15	.15	40	.16	∞
24	.14	.14			
25	.15	.14			

Cartridges 1-36 and 41-46 vibrated breech end up
Cartridges 37-38 vibrated in horizontal position
Cartridges 39-40 vibrated with breech end down

TABLE 1

TABLE 2

DOUGLAS BOMB EJECTOR CARTRIDGE MK 1 MOD 1
PROPELLER CLEARANCE AND HORIZONTAL DISTANCE TO PROPELLER-PLANE INTERSECTION

Cartridge No.	Bomb Weight	Clearance (ft)	Horiz. Range	Cartridge No.	Bomb Weight	Clearance (ft)	Horiz. Range
4	2000	2.86	6' 2"	52	2000	3.06	6' 3"
5	2000	2.14	5' 3"	54	2000	2.96	6' 4"
6	2000	2.24	5' 5"	55	2000	2.96	6' 4"
7	500	6.82	13' 0"	56	2000	3.16	6' 5"
8	2000	2.33	5' 10"	57	2000	2.72	5' 11"
11	2000	2.37	5' 8"	58	2000	2.58	5' 9"
12	2000	2.67	5' 10"	59	2000	2.86	6' 3"
13	2000	2.50	5' 8"	60	2000	2.92	6' 3"
14	2000	2.77	6' 1"	61	2000	2.26	5' 6"
15	2000	2.28	5' 7"	62	2000	2.33	5' 5"
16	2000	2.77	6' 0"	63	2000	3.35	6' 10"
17	500	6.12	11' 1"	66	2000	4.00	7' 6"
18	1000	5.20	9' 11"	67	2000	5.98?	11' 6"?
19	2000	2.94	6' 3"	68	2000	3.86	7' 6"
20	2000	3.45	6' 10"	69	2000	3.98	7' 6"
23	2000	3.06	6' 7"	70	2000	3.88	7' 6"
24	2000	3.06	6' 6"	71	2000	2.77	6' 0"
25	2000	2.82	6' 1"	72	2000	3.77	7' 2"
26	2000	3.11	6' 5"	73	2000	3.79	7' 3"
27	2000	2.72	5' 11"	74	2000	2.80	6' 0"
28	500	7.04	13' 9"	76	2000	2.94	6' 2"
29	2000	3.11	6' 7"	77	2000	2.72	6' 0"
30	2000	3.26	6' 10"	78	2000	2.77	6' 1"
31	2000	2.60	5' 10"	79	2000	2.19	5' 4"
32	2000	2.58	5' 10"	80	2000	2.58	5' 11"
33	2000	2.33	5' 6"	81	500	7.15	14' 0"
35	2000	2.19	5' 4"	82	1000	*2.24	*5' 8"
36	500	7.04	13' 7"	85	1000	5.22	9' 5"
47	2000	3.81	7' 5"	91	1000	4.21	9' 0"
49	2000	4.03	7' 6"	98	2000	#1.65	#4' 9"
50	2000	3.86	7' 6"	99	2000	#1.06	#4' 1"
51	2000	2.52	5' 9"	100	2000	#1.06	#4' 1"

*means 1/2 powder bad   # means 3/4 powder load   ? means questionable meas.

TABLE 3

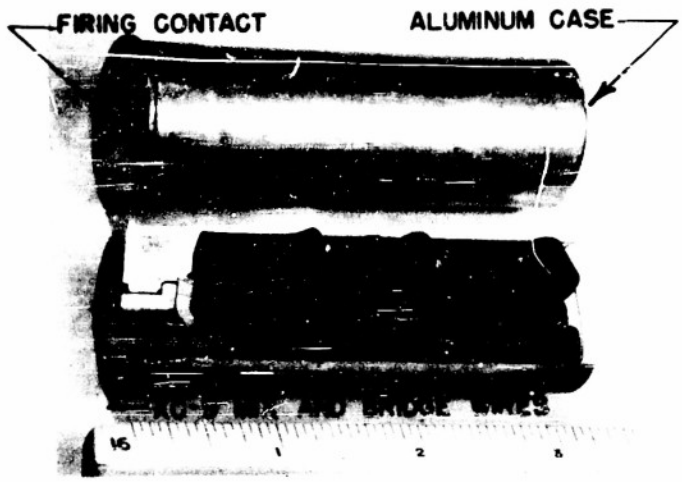
DOUGLAS BOMB EJECTOR CARTRIDGE MK 1 MOD 1
UNBURNED POWDER AFTER FIRING

Cartridge No.	Conditioning	Unburned Powder Grams	Bomb Weight Lbs.
5	-65°F Vibrated	0.70	2000
6	-65°F Vibrated	0.30	2000
7	-65°F Vibrated	9.56	500
9	0°F Vibrated	0.28	2000
11	0°F Vibrated	0.21	2000
12	0°F Vibrated	0.60	2000
13	0°F Vibrated	0.11	2000
15	0°F Vibrated	0.74	2000
16	0°F Vibrated	0.70	2000
17	0°F Vibrated	8.81	500
29	70°F Vibrated	0.13	2000
31	70°F Vibrated	0.23	2000
35	70°F Vibrated	0.60	2000
54	0°F Non-Vibrated	0.20	2000
57	0°F Non-Vibrated	0.52	2000
58	0°F Non-Vibrated	0.31	2000
62	0°F Non-Vibrated	0.40	2000
68	70°F Non-Vibrated	0.12	2000
75	70°F Non-Vibrated	0.20	2000
76	70°F Non-Vibrated	0.35	2000
78	70°F Non-Vibrated	0.25	2000
79	70°F Non-Vibrated	0.30	2000
80	70°F Non-Vibrated	0.21	2000
81	70°F Non-Vibrated	0.50	500
98	70°F 3/4 Load	3.89	2000
100	70°F 3/4 Load	4.27	2000

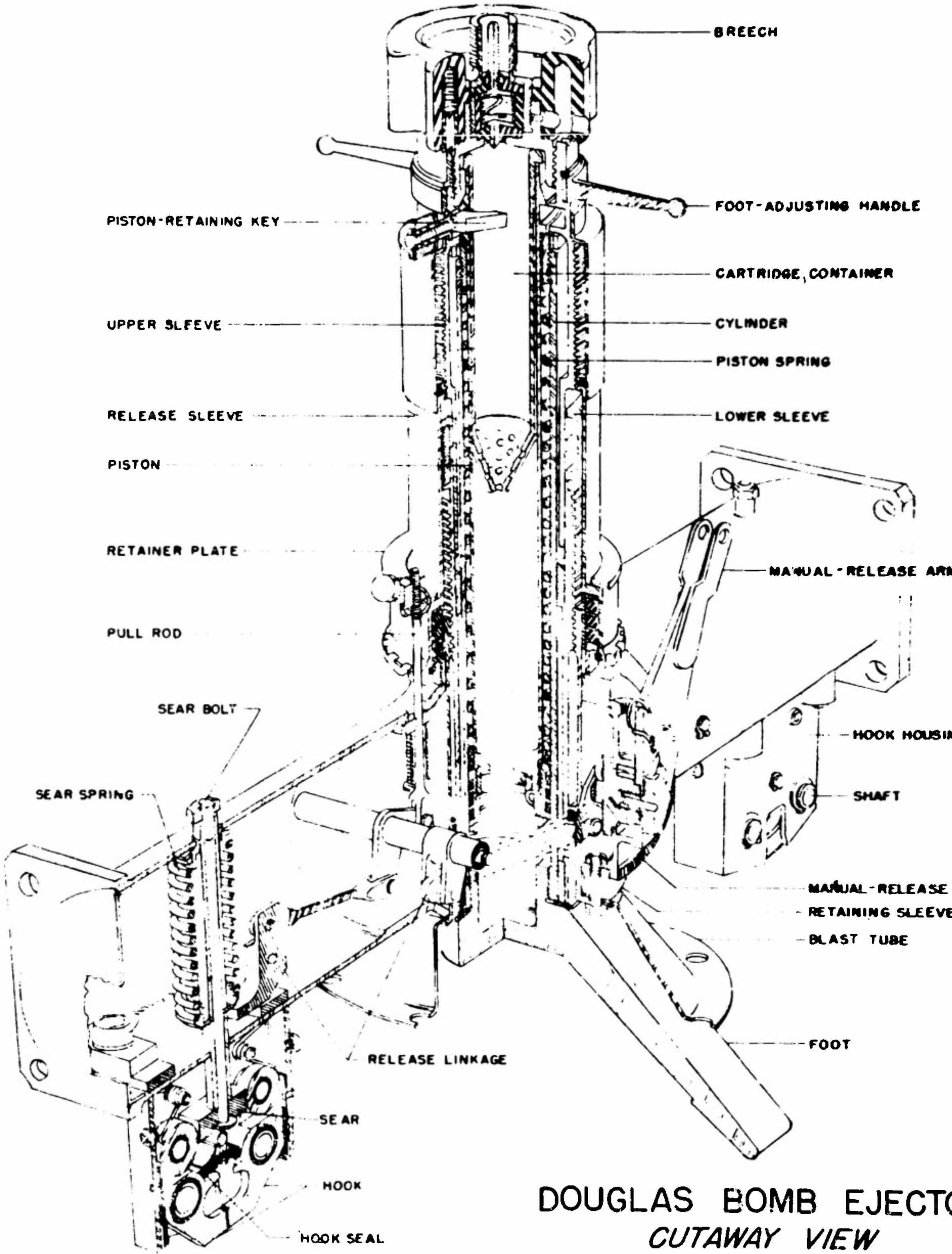
Smokeless Powder in Fully-Loaded Round - 26.4 Grams

BOMB EJECTOR CARTRIDGE MK I MOD I

RADIOGRAPH



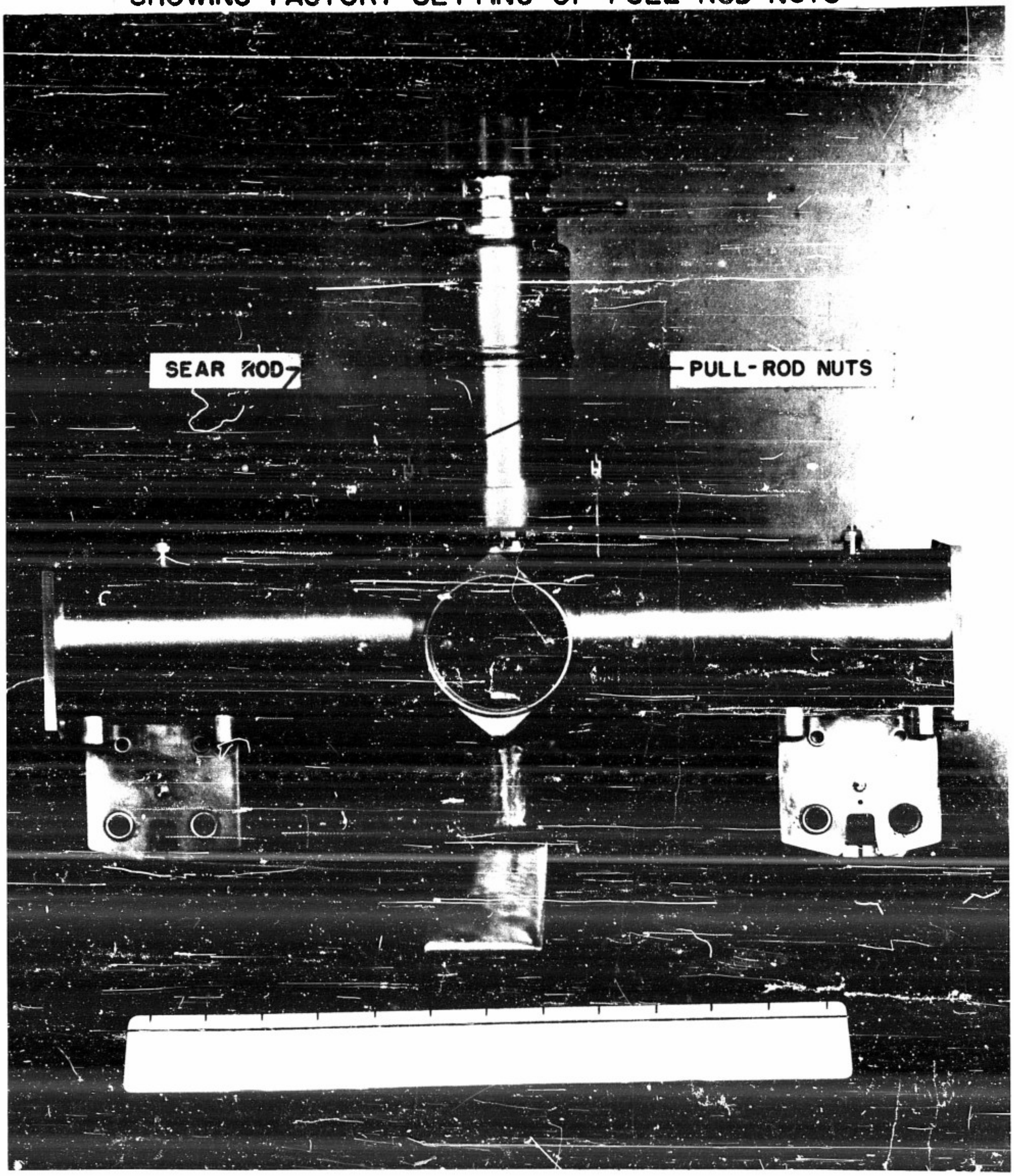
AFTER FIRING

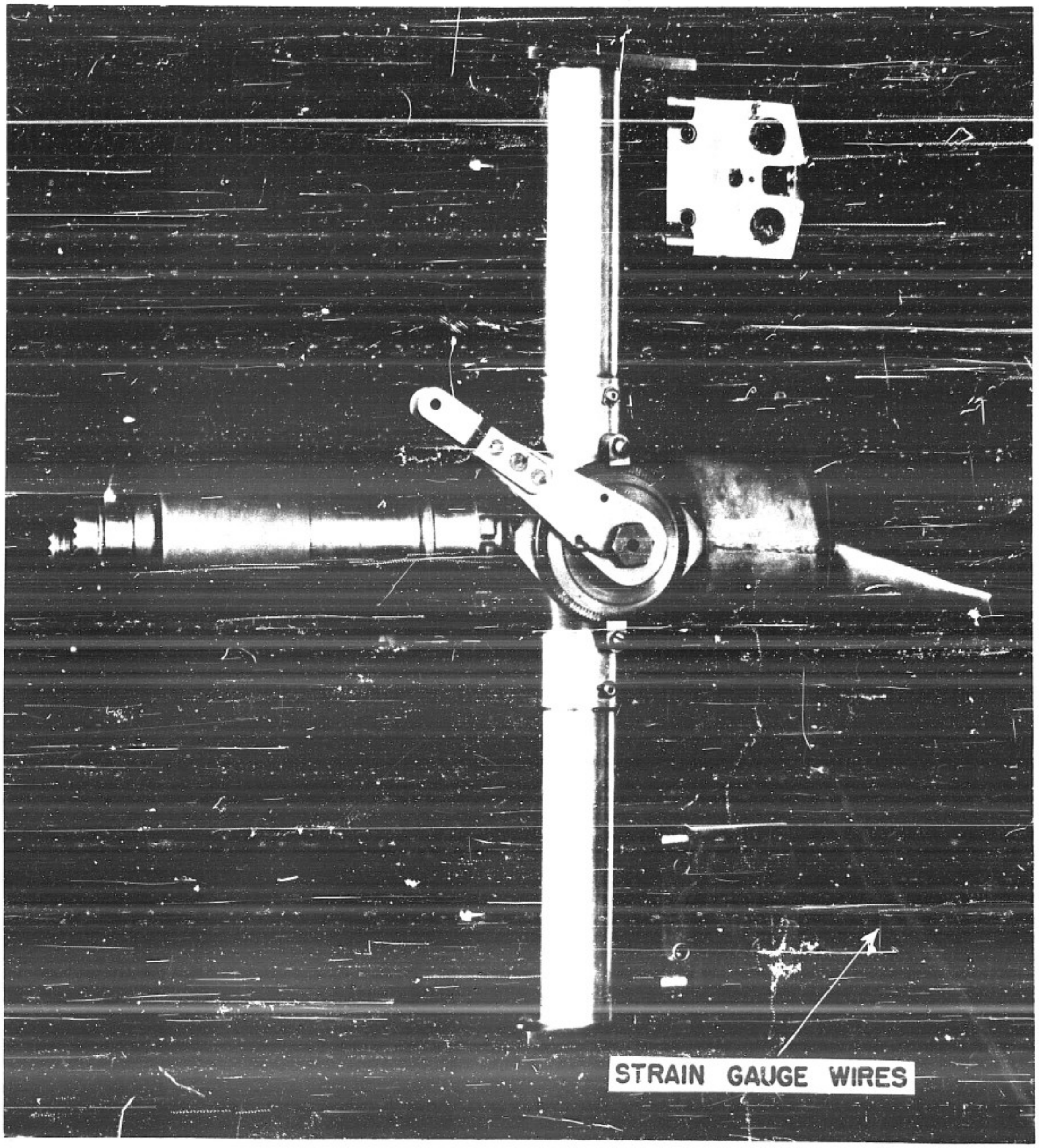


DOUGLAS BOMB EJECTOR
CUTAWAY VIEW

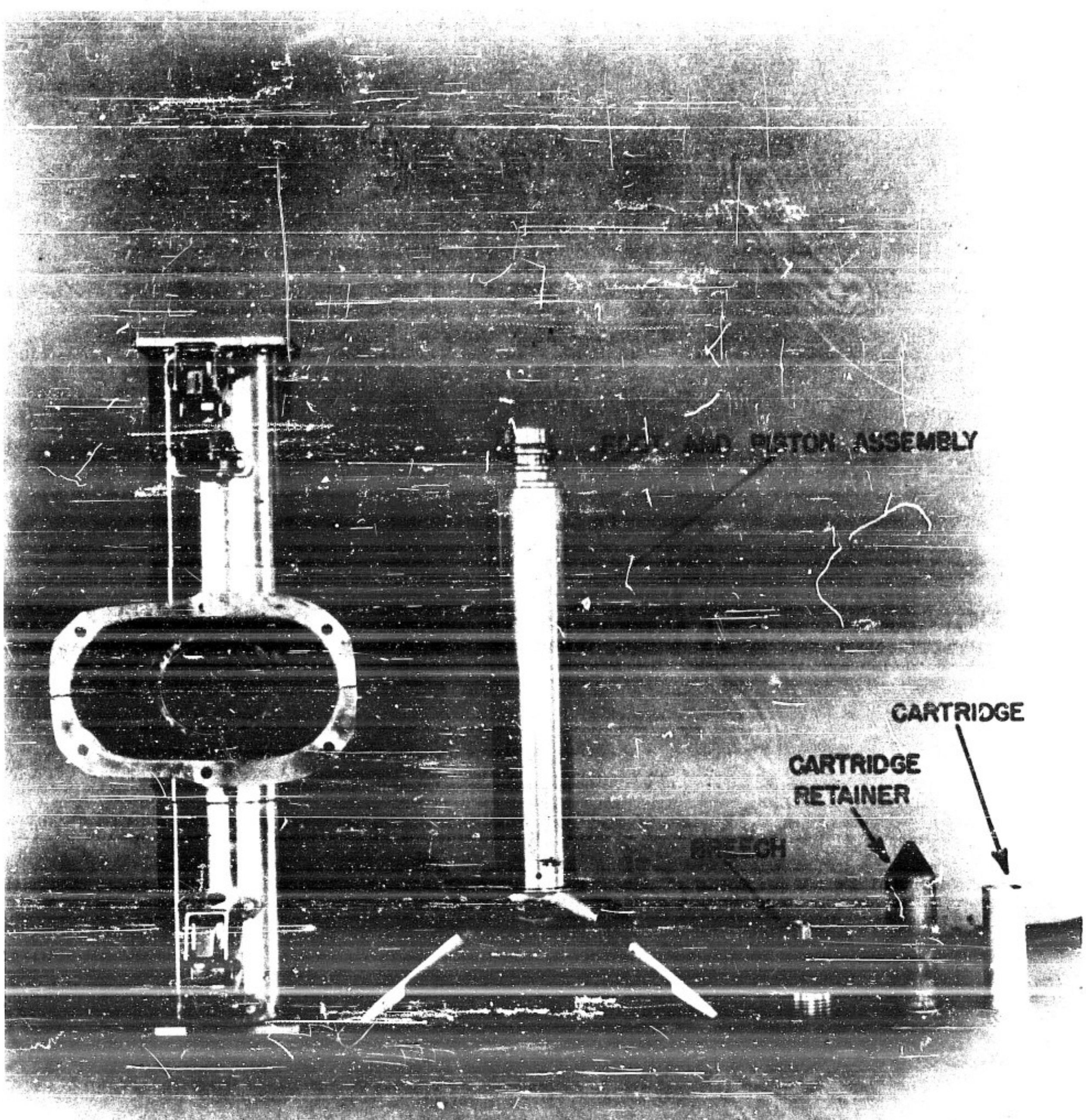
DOUGLAS BOMB EJECTOR

SHOWING FACTORY SETTING OF PULL-ROD NUTS

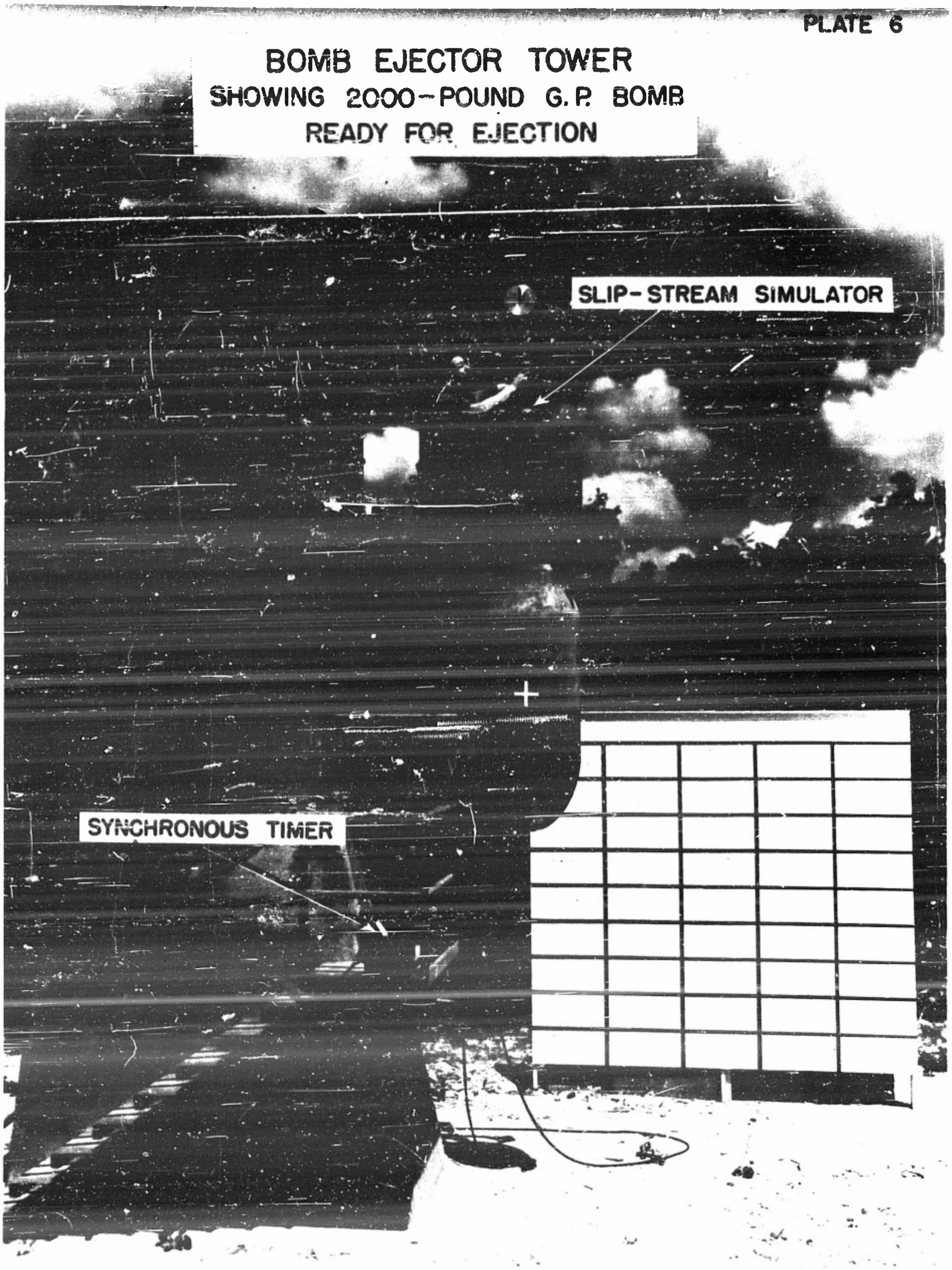


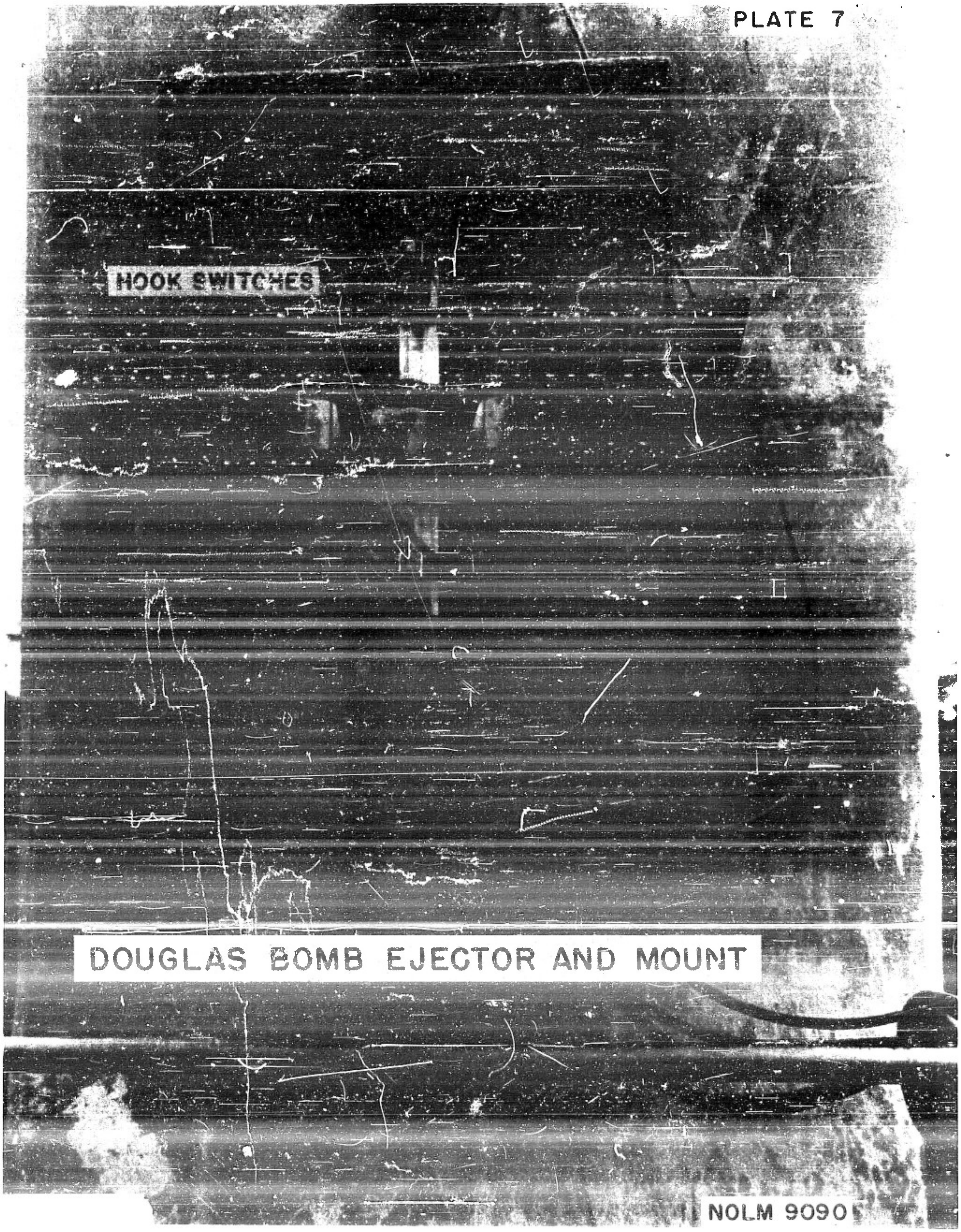


DOUGLAS BOMB EJECTOR
SHOWING SETTING OF PULL-ROD NUTS
NECESSARY TO PREVENT SEAR-ROD MOVEMENT

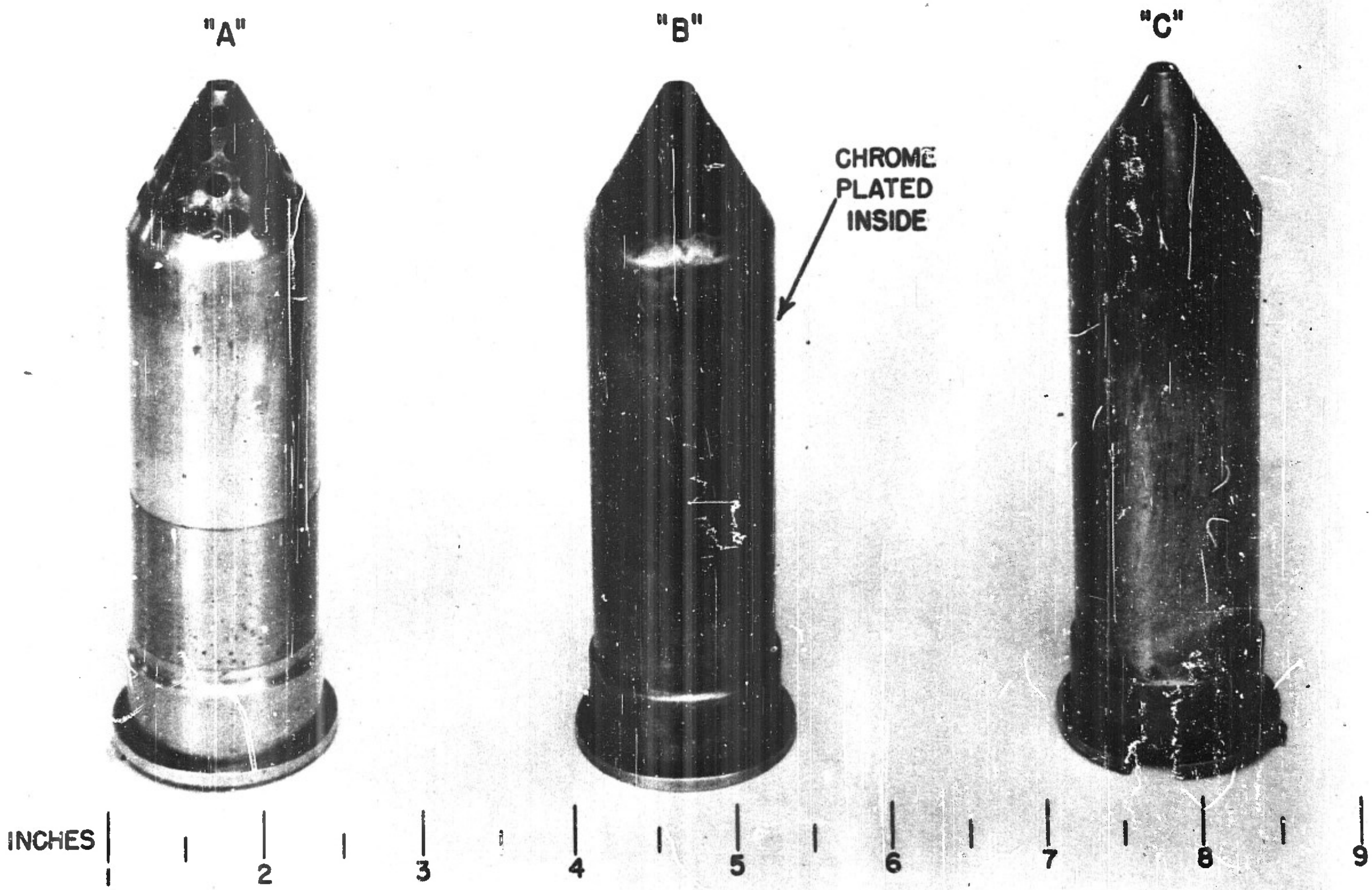


DOUGLAS BOMB EJECTOR
EXPLODED VIEW
SHOWING LOCATION OF STRAIN GAUGES

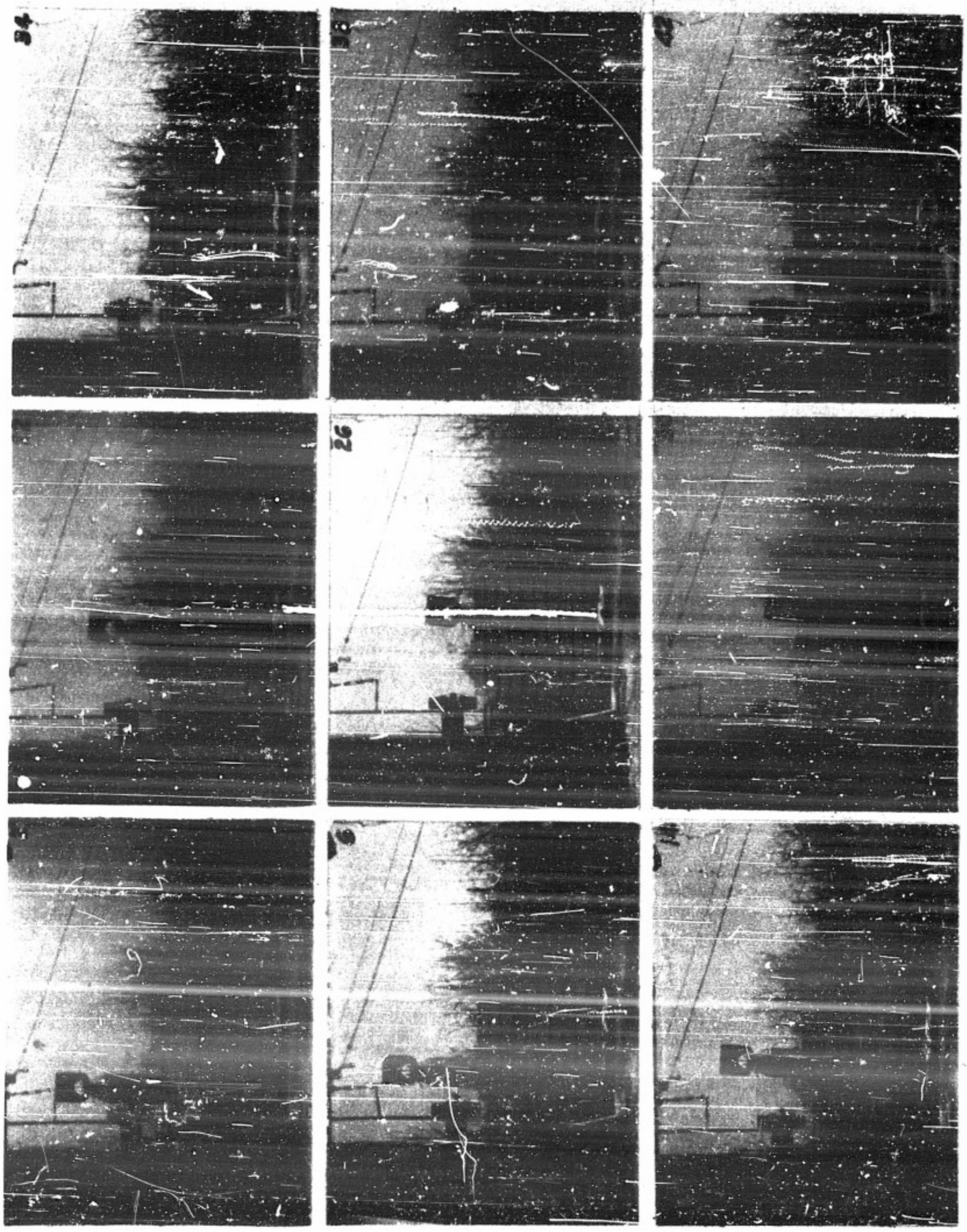

BOMB EJECTOR TOWER
SHOWING 2000-POUND G.P. BOMB
READY FOR EJECTION
SLIP-STREAM SIMULATOR
SYNCHRONOUS TIMER



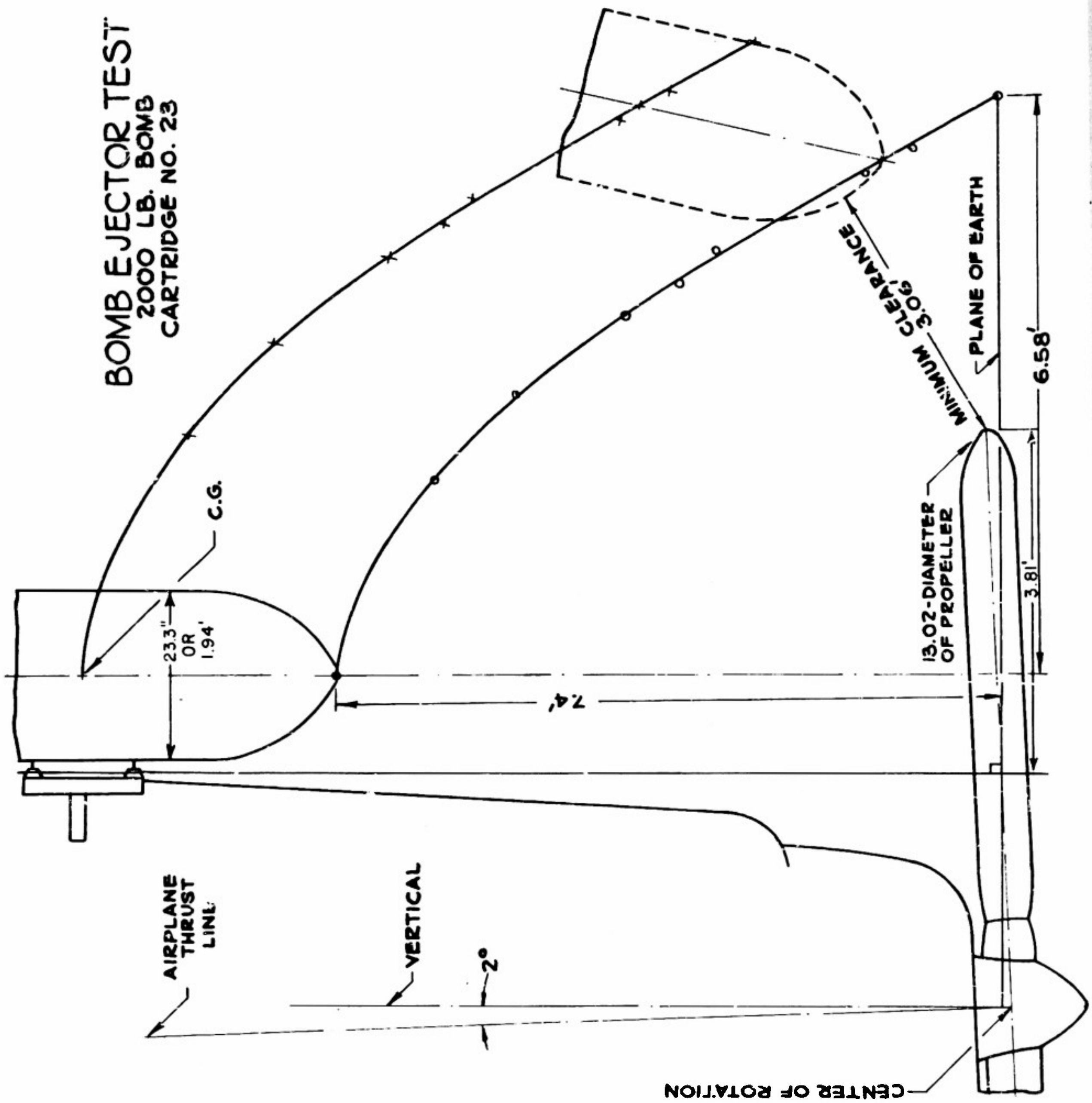
DOUGLAS BOMB EJECTOR AND MOUNT

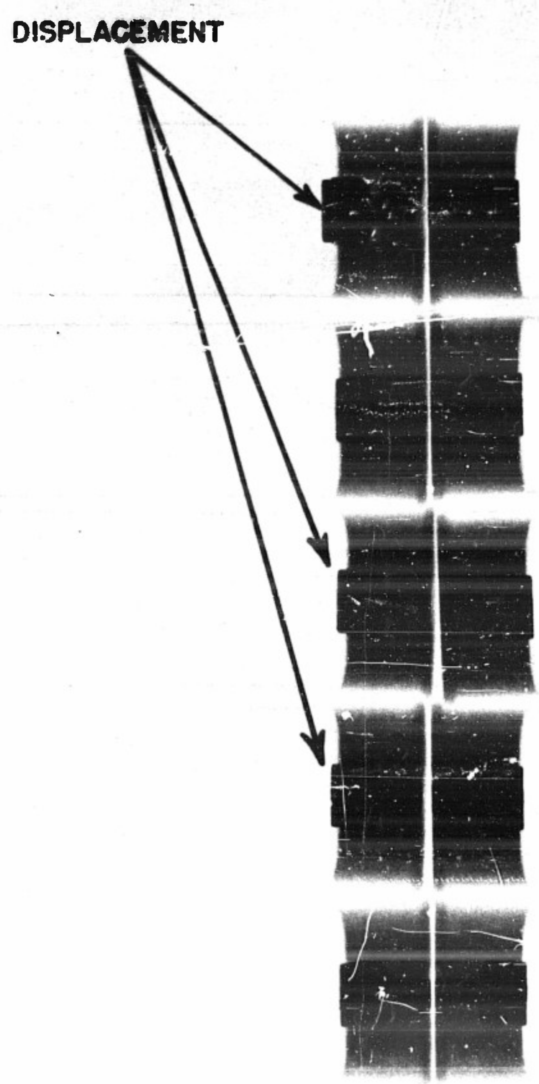


D.B.E. CARTRIDGE RETAINERS
THREE TYPES USED DURING EXPERIMENTS

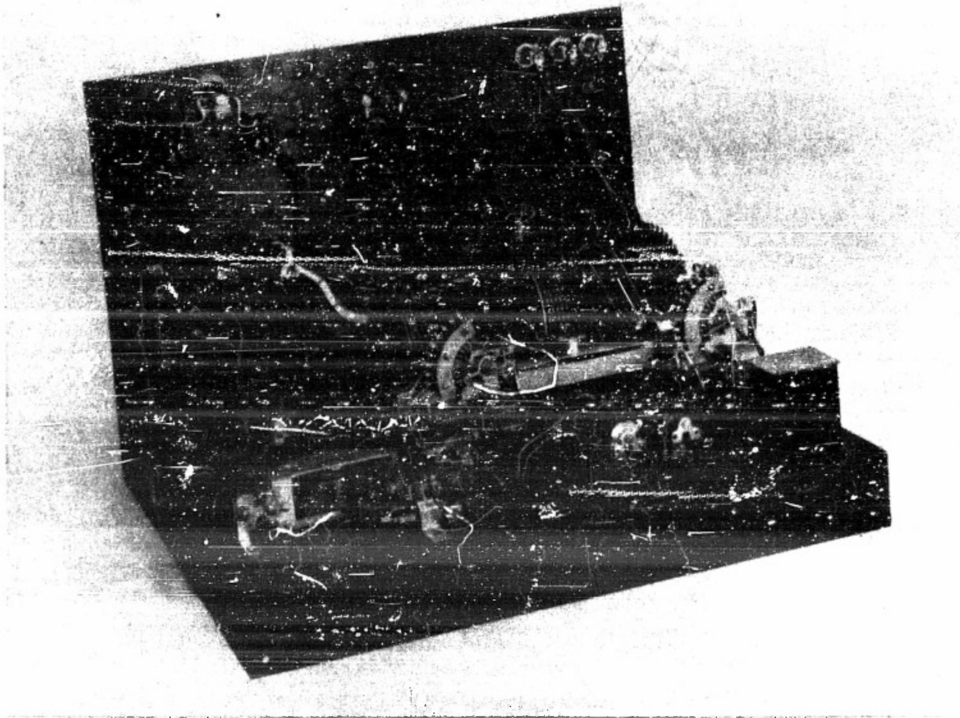


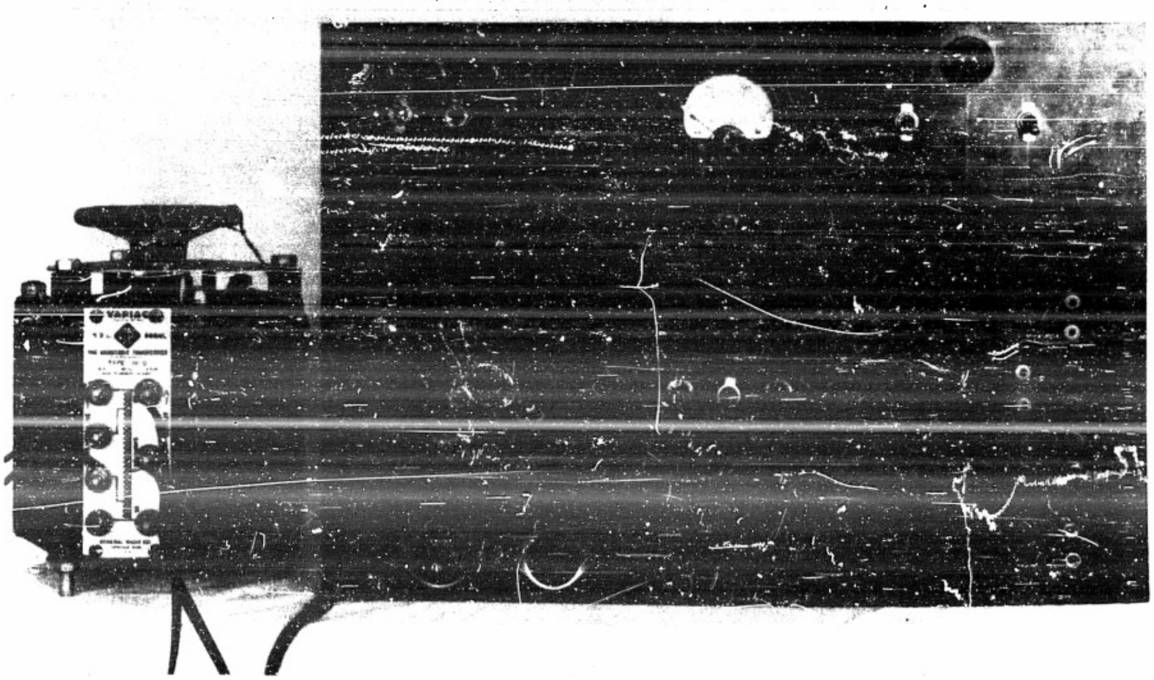
2000-POUND BOMB EJECTION


BOMB EJECTOR TEST
2000 LB. BOMB
CARTRIDGE NO. 23
C.G.
23.3" OR 1.94'
7.4'
MINIMUM CLEARANCE 3.06'
PLANE OF EARTH
6.58'
3.81'
13.02-DIAMETER OF PROPELLER
AIRPLANE THRUST LINE
VERTICAL
2°
CENTER OF ROTATION

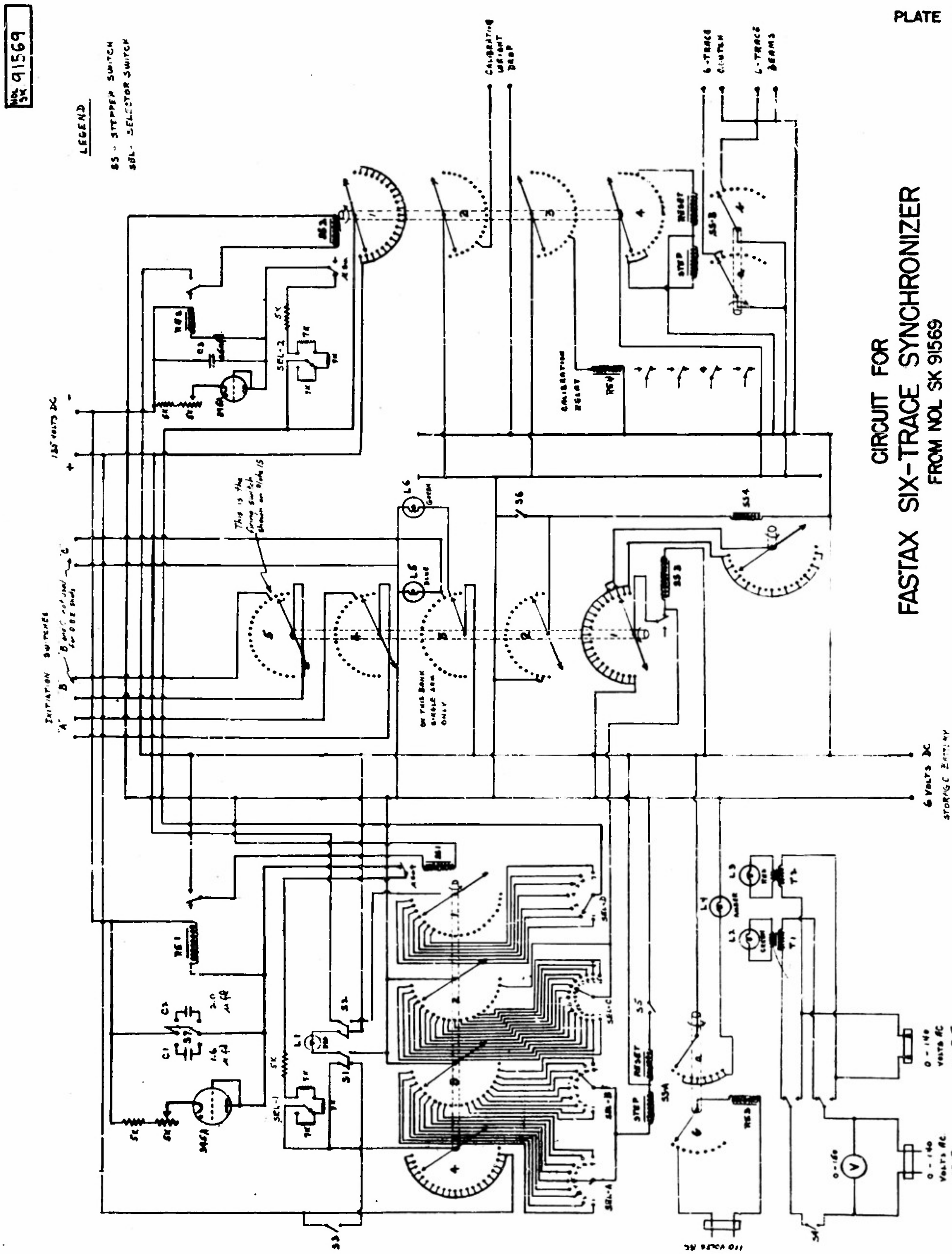


RADIOGRAPH SHOWING DISPLACEMENT
OF CONTACT AND PRIMER ASSEMBLIES
CAUSED BY VIBRATION





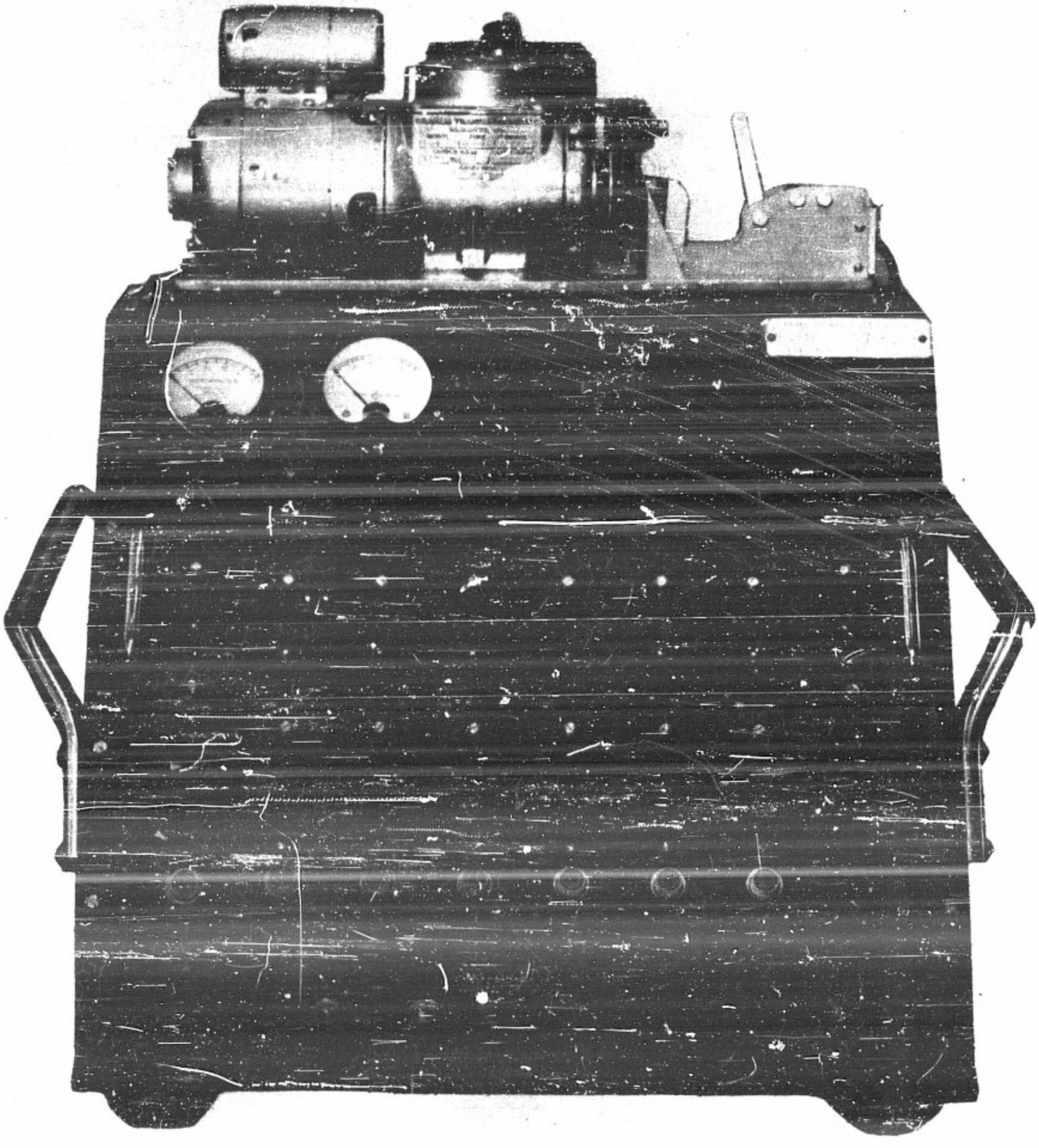
FASTAX SIX-TRACE AUTOMATIC SYNCHRONIZER



CIRCUIT FOR
FASTAX SIX-TRACE SYNCHRONIZER
FROM NOL SK 91569

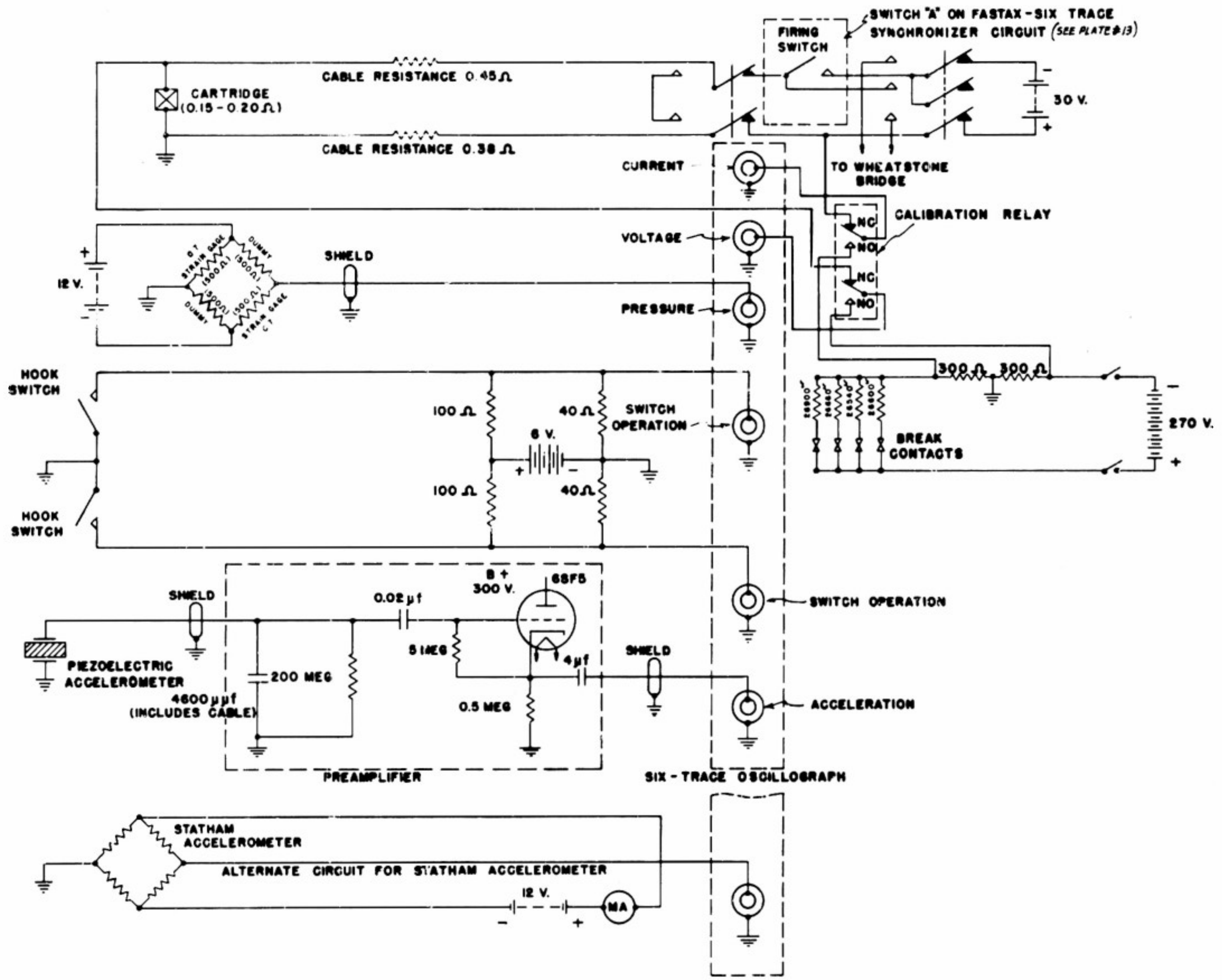
PLATE 14

SIX-TRACE CATHODE-RAY OSCILLOGRAPH

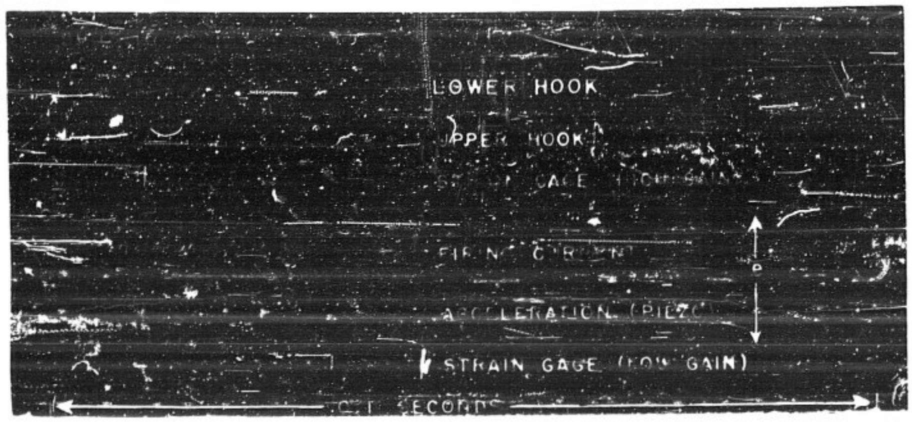


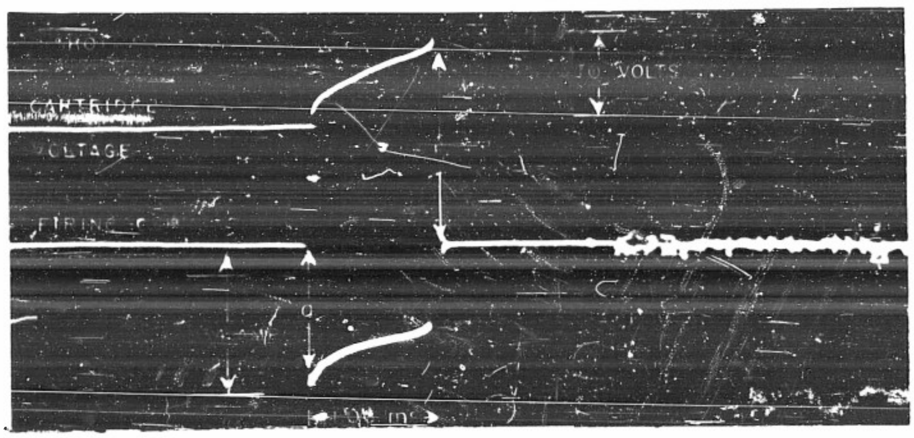
INSTRUMENTATION FOR BOMB-EJECTOR CARTRIDGE MK I MOD I

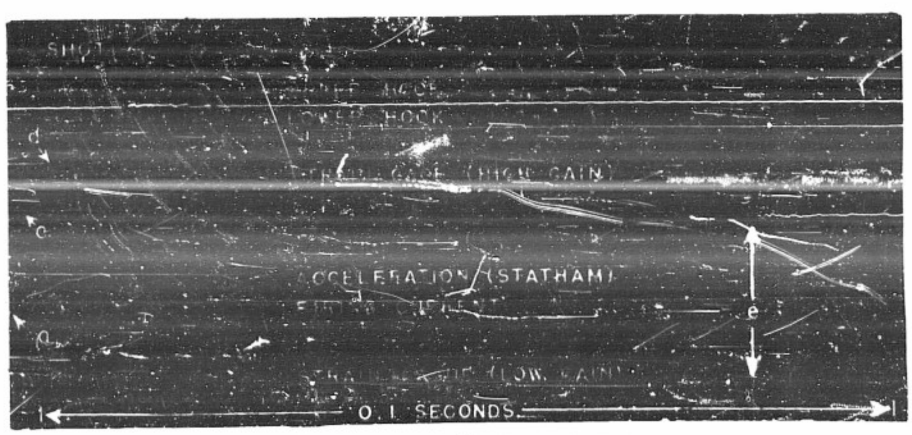
(FOR DOUGLAS BOMB-EJECTOR)



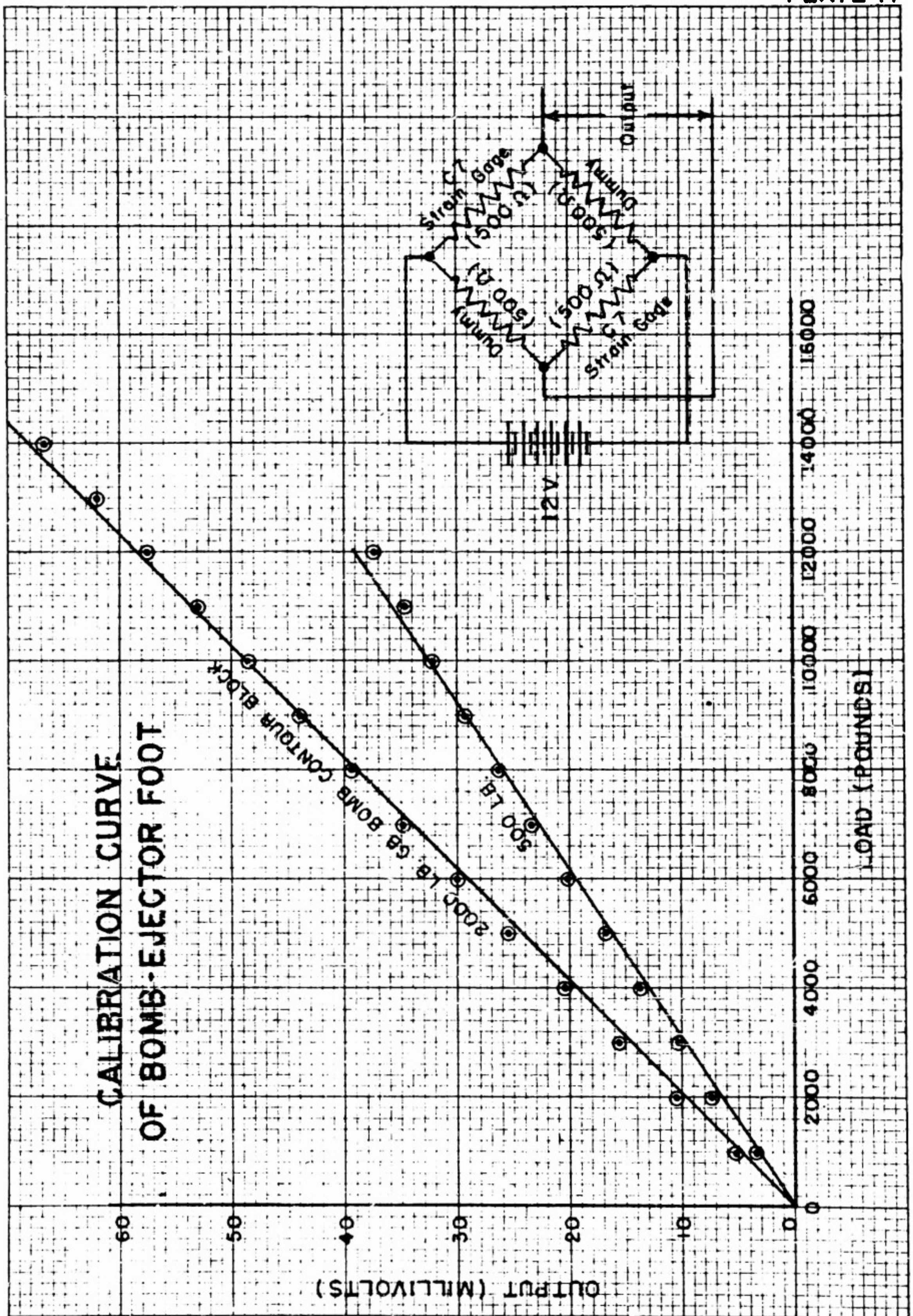
SAMPLE OSCILLOGRAMS







a–FIRING CURRENT APPLIED
b–BRIDGE WIRE BURNS OUT
c–START PRESSURE BUILD-UP
d–HOOKS OPEN
e–BOMB LEAVES EJECTOR FOOT


CALIBRATION CURVE
OF BOMB-EJECTOR FOOT
2000 LB. GB BOMB CONTOUR BLOCK
500 LB.
OUTPUT (MILLIVOLTS)
LOAD (POUNDS)
0
10
20
30
40
50
60
0
2000
4000
6000
8000
10000
12000
14000
16000
Strain Gage
C-7
(500 Ω)
Dummy
(500 Ω)
Dummy
(500 Ω)
(500 Ω)
C-7
Strain Gage
Output
12V

SHOT NO.	CARTRIDGE NO.	TEMPERATURE TREATED IN F°	TREATMENT RECEIVED	CARTRIDGE RETAINER USED	MEASURED RANGE FT.	MEASURED RANGE IN.	TIME OF HOOP OPENING IN MS. TOP	TIME OF HOOP OPENING IN MS. BOTTOM	TIME TO REACH 3000 PSI PRESSURE MS.	PRESSURE AT WHICH HOOPS OPENED (PSI) TOP	PRESSURE AT WHICH HOOPS OPENED (PSI) BOTTOM	TIME OF PRESSURE READING AT: RISE	TIME OF PRESSURE READING AT: PEAK	TIME OF PRESSURE READING AT: FALL TO ZERO	TIME OF PIEZO-READING AT: RISE	TIME OF PIEZO-READING AT: PEAK	TIME OF PIEZO-READING AT: FALL TO ZERO	TIME OF STATHAM READINGS AT: RISE	TIME OF STATHAM READINGS AT: PEAK	TIME OF STATHAM READINGS AT: FALL TO ZERO	PEAK VALUES PRESSURE PSI	PEAK VALUES PRESSURE 43	PEAK VALUES ACCELERATION B&E	PEAK VALUES ACCELERATION STATHAM	BREAK TIME AND MAX. CURRENT
1	65	70°		A	7	6	—	—	5.05	—	—	5.03	65.74	74.14	—	—	—	—	—	—	5406	6.70	—	—	1.83 30.35
2	66	70°		A	7	6	—	—	11.05	—	—	11.03	65.31	73.36	2.88	39.19	76.52	—	—	—	5455	6.74	7.43	—	0.78 33.41
3	47	0		A	7	5	No Record →																		
4	48	0		A	7	6	No Record →																		
5	49	0		B	7	6	No Record →																		
6	50	0		B	7	6	No Record →																		
7	67	70		B	(11	6)?	4.54	4.86	3.80	164	182	3.33	42.87	68.19	4.04	34.18	68.23		Statham Accelerometer was not used here		3454	4.88	7.00	—	0.71 34.39
8	68	70		B	7	6	4.93	5.27	3.00	559	633	2.40	45.00	70.30	2.60	31.00	70.15				4710	5.82	11.36	—	1.00 25.83
9	69	70		B	7	6	4.26	4.42	2.04	547	562	1.72	54.55	67.70	2.46	31.00	72.22				4837	5.98	10.08	—	0.57 28.34
10	1	-65	VIBRATED	B	6	3	8.47	8.47	5.75	223	223	3.82	72.10	85.40	—	—	—				4130	5.10	—	—	0.62 31.03
11	70	70		B	7	6	4.45	4.38	1.75	417	383	1.12	53.12	69.00	3.59	32.81	73.50				5341	6.66	6.90	—	0.52 29.31
12	2	-65	VIBRATED	B	6	3	16.12	15.62	13.85	130	155	12.85	72.80	94.71	13.85	68.01	104.53				2779	3.44	5.71	—	3.57 24.24
13	3	-65	"	B	6	9	6.75	6.75	4.35	240	240	3.48	60.00	78.80	5.00	50.50	80.75				4076	5.04	7.74	—	0.62 28.59
14	72	70		B	7	2	5.40	5.60	2.04	444	541	1.63	46.40	70.51	3.14	30.00	72.50				4867	6.00	7.68	—	0.84
15	4	-65	VIBRATED	B	6	2	5.46	3.78	2.98	316	166	2.55	54.08	81.02	3.67	48.16	83.88				3709	4.58	6.71	—	0.88 30.47
16	51	0		C	5	9	7.36	6.82	3.15	963	876	1.86	53.29	88.25	4.58	40.63	92.21				2685	3.32	5.88	—	0.52 29.71
17	52	0		C	6	3	6.52	5.04	2.61	417	338	1.56	52.69	82.72	2.95	18.13	84.14				3482	4.30	5.15	—	0.61 29.38
18	71	70		C	6	0	11.93	11.49	8.74	157	176	5.75	47.41	88.30	9.34	47.24	101.15				3040	3.75	5.08	—	1.21 29.01
19	73	70		B	7	3	—	—	2.29	—	—	1.89	38.96	69.77	3.72	23.08	71.63				4328	5.34	7.51	—	0.72 30.37
20	74	70		C	6	0	4.18	5.24	2.23	654	805	1.95	45.26	79.94	3.56	33.98	82.21				4245	5.26	5.95	—	0.84 30.29
21	19	70	VIBRATED	B	6	3	8.55	7.84	4.87	1628	1367	3.97	43.15	79.08	—	—	—				4492	5.55	—	—	0.61 29.69
22	20	70	"	C	6	10	4.89	6.18	2.37	1094	1131	1.58	40.18	82.00	—	—	—				3688	4.54	—	—	0.53 31.43
23	76	70		B	6	2	7.02	6.46	3.34	1997	1515	2.65	47.35	73.40	4.40	34.54	73.43				4338	5.36	7.53	—	0.78 40.15
24	75	70		B	6	7	6.23	5.65	2.97	1645	1371	2.89	46.55	74.16	4.16	31.56	76.66				5045	6.22	7.20	—	1.11 35.70
25	9	0	VIBRATED	B	7	1	7.65	6.15	2.69	1266	659	2.03	42.48	71.7	3.69	22.30	75.99				3903	4.82	[illegible]	—	0.53 30.87
26	10	0	"	B	6	2	5.40	4.63	1.64	1632	1469	1.24	38.30	78.41	3.16	31.57	79.64				4556	5.63	4.87	—	0.47 35.43
27	11	0	"	C	5	8	5.01	5.85	2.50	968	1148	2.40	50.92	91.03	3.62	37.41	92.87	3.40	40.53	96.13	3043	3.68	4.28	4.68	0.50 34.57
28	29	70	VIBRATED	C	6	7	5.70	5.04	1.46	1790	1377	1.06	41.72	73.06	1.33	32.76	80.27	—	—	—	4158	5.04	5.56	—	0.53 30.64
29	30	70	"	B	6	10	5.45	5.78	2.02	1499	1690	1.91	36.59	75.34	3.60	34.20	77.38	3.73	34.33	82.23	4498	5.45	5.19	7.07	0.76 24.70
30	53	0		C	4	10	7.60	7.20	3.30	1316	1203	3.17	50.92	92.35	5.36	35.67	99.29	6.97	42.87	101.11	3821	4.73	3.78	4.63	0.58 29.55
31	54	0		B	6	4	—	4.93	2.05	—	1227	1.33	38.93	77.33	2.72	33.55	87.12	4.53	30.53	86.40	3789	4.67	5.82	8.86	0.56
32	55	0		B	6	4	8.42	8.42	5.16	432	432	5.00	43.53	78.80	5.68	40.00	86.36	8.34	40.63	86.36	3456	4.27	6.90	8.12	0.54
33	56	0		B	6	5	6.00	5.03	1.68	2015	2015	1.38	41.18	74.93	3.03	28.93	88.71	4.68	30.20	82.57	4568	5.65	6.05	6.65	0.55
34	57	0		B	5	11	6.06	5.85	3.81	1177	1044	2.71	41.34	81.16	5.60	36.97	89.03	6.50	37.76	87.41	3986	4.94	6.29	6.32	0.43
35	12	0	VIBRATED	B	5	10	5.33	4.56	2.35	1454	1163	1.69	52.87	79.93	1.91	37.73	71.09	4.87	40.00	86.64	4188	6.18	4.61	5.56	0.65
36	31	70	VIBRATED	B	6	10	15.09	14.34	10.94	1149	1005	10.51	51.43	89.80	—	—	—	4.26	48.71	96.00	4026	4.98	—	6.72	1.37
37	77	70		B	6	0	5.34	5.06	1.40	2010	1939	1.04	25.84	74.63	—	—	—	5.00	30.62	81.74	4308	5.31	—	9.07	0.76
38	58	0		B	5	9	6.72	5.22	1.81	1650	1339	1.67	34.53	79.17	1.94	27.50	80.28	5.28	35.28	87.22	3565	4.40	5.26	7.51	0.53
39	5	-65	VIBRATED	B	5	3	8.96	7.48	4.62	1442	883	4.35	55.00	90.00	4.60	37.35	90.00	8.00	38.46	97.77	3589	4.44	4.15	5.65	0.65
40	13	0	VIBRATED	B	5	8	6.05	5.74	2.61	1037	934	2.41	46.42	81.90	3.21	38.58	84.26	5.99	36.08	87.27	3987	4.92	5.02	6.98	0.45
41	14	0	"	B	6	1	5.00	4.58	3.06	218	145	2.50	40.28	74.72	4.58	30.69	71.25	5.00	34.17	80.75	3364	4.15	5.21	9.18	0.42
42	21	160	VIBRATED	B	6	6	5.77	4.67	1.30	2155	1529	1.18	34.29	68.13	—	—	—	4.94	26.24	74.09	3858	4.77	—	8.64	0.52
43	23	160	"	B	6	7	76.38	76.21	No Record →									76.44	103.20	149.41	—	—	—	11.25	2.10
44	22	160	"	B	6	8	27.33	26.30	No Record →									24.87	56.22	101.65	—	—	—	10.05	1.11
45	78	70		B	6	1	6.16	5.46	No Record →									4.77	33.92	83.09	—	—	—	9.20	0.63
46	32	70	VIBRATED	B	5	10	6.19	5.25	No Record →									4.42	32.32	85.30	—	—	—	7.43	0.63
47	15	0	VIBRATED	B	5	7	7.58	6.17	No Record →									5.40	36.00	96.24	—	—	—	4.67	0.72
48	16	0	"	B	6	0	6.81	4.80	2.95	363	441	2.40	38.26	81.18	—	—	—	6.06	38.13	96.40	2423	2.94	—	6.45	0.51
49	6	-65	VIBRATED	B	5	5	7.23	5.49	2.44	1287	768	2.01	38.15	88.28	—	—	—	5.74	37.78	96.13	2456	2.97	—	4.89	0.50
50	59	0		B	6	2½	7.79	5.05	2.38	2214	1220	1.98	39.97	76.40	—	—	—	5.33	37.18	86.93	3730	4.60	—	9.43	1.02
51	60	0		B	6	3	7.09	5.57	3.04	1028	492	2.46	37.34	77.47	—	—	—	5.57	38.35	86.58	3395	4.12	—	7.73	1.07
52	24	160	VIBRATED	B	6	6	32.61	—	27.99	1572	—	27.66	47.01	99.49	—	—	—	31.60	49.76	108.76	3508	4.25	—	6.78	1.36
53	33	70	VIBRATED	B	5	6	—	7.79	4.23	—	1036	3.91	46.34	85.15	6.22	41.79	93.21	7.71	41.29	93.91	2864	3.54	4.20	6.83	0.70
54	25	160	VIBRATED	B	6	1	20.00	18.70	16.10	1602	913	15.58	48.05	55.45	—	—	—	19.74	45.45	93.51	3466	4.29	—	7.93	1.30
55	26	160	"	B	6	5	5.14	3.97	2.08	1335	657	1.69	25.97	69.61	—	—	—	4.94	32.99	77.14	2340	3.50	—	16.73	0.49
56	79	70		B	5	4	—	—	—	1145	895*	No Record →													8.29
57	80	70		B	5	11	13.31	12.06	9.62	1300	849	8.94	No Accelerometer Readings or Completed Strain Gage Trace →												5.93
58	61	0		B	5	6	14.75	13.43	10.82	—	1208	10.44	→												9.59 4.56
59	62	0		B	5	5	19.00	17.34	14.76	1320	901	13.73	→												11.41 1.46
60	35	70	VIBRATED	B	5	4	42.68	41.25	38.65	—	1152	38.00	→												35.00
61	98	¾ Load		B	4	9	17.48	16.03	13.24	650	277	12.66	42.14	—	—	—	—	15.69	51.38	—	2054	4.54	—	5.82	11.38 3.74
62	99	Ambient Temperature		B	4	1	23.34	22.10	19.50	743	541	17.48	43.91	118.40	—	—	—	21.26	58.04	128.25	1980	2.44	—	2.95	17.42 2.98
63	100	No Vibration		B	4	1	37.51	36.00	31.57	920	645	30.00	68.86	128.00	—	—	—	35.71	67.36	136.57	2060	1.66	—	3.42	30.24 3.66
64	27	160	VIBRATED	B	5	11	37.35	35.95	33.38	—	1083	32.83	—	—	No Accelerometer Readings →										99.58
65	36	500 lb. Bomb 70	VIBRATED	B	13	7	43.70	44.34	43.63	1974	2435	40.00	65.60	86.81 →							4121	20.78			39.66 3.00
66	28	160	VIBRATED	B	13	9	22.44	19.33	17.56	2689	1729	17.53	34.67	56.64 →							4467	42.4			15.78 2.99
67	81	70		B	14	0	27.09	26.48	28.77	2014	1762	24.48	42.66	63.43 →							5088	35.59			22.91 3.03
68	17	0	VIBRATED	B	11	1	14.63	13.90	11.34	1793	1379	10.49	41.10	59.02 →							3557	17.89			10.24
69	7	-65	VIBRATED	B	13	0	45.69	45.89	42.34	1793	1862	42.11	45.45	44.74 →							3824	19.23			41.16 3.23

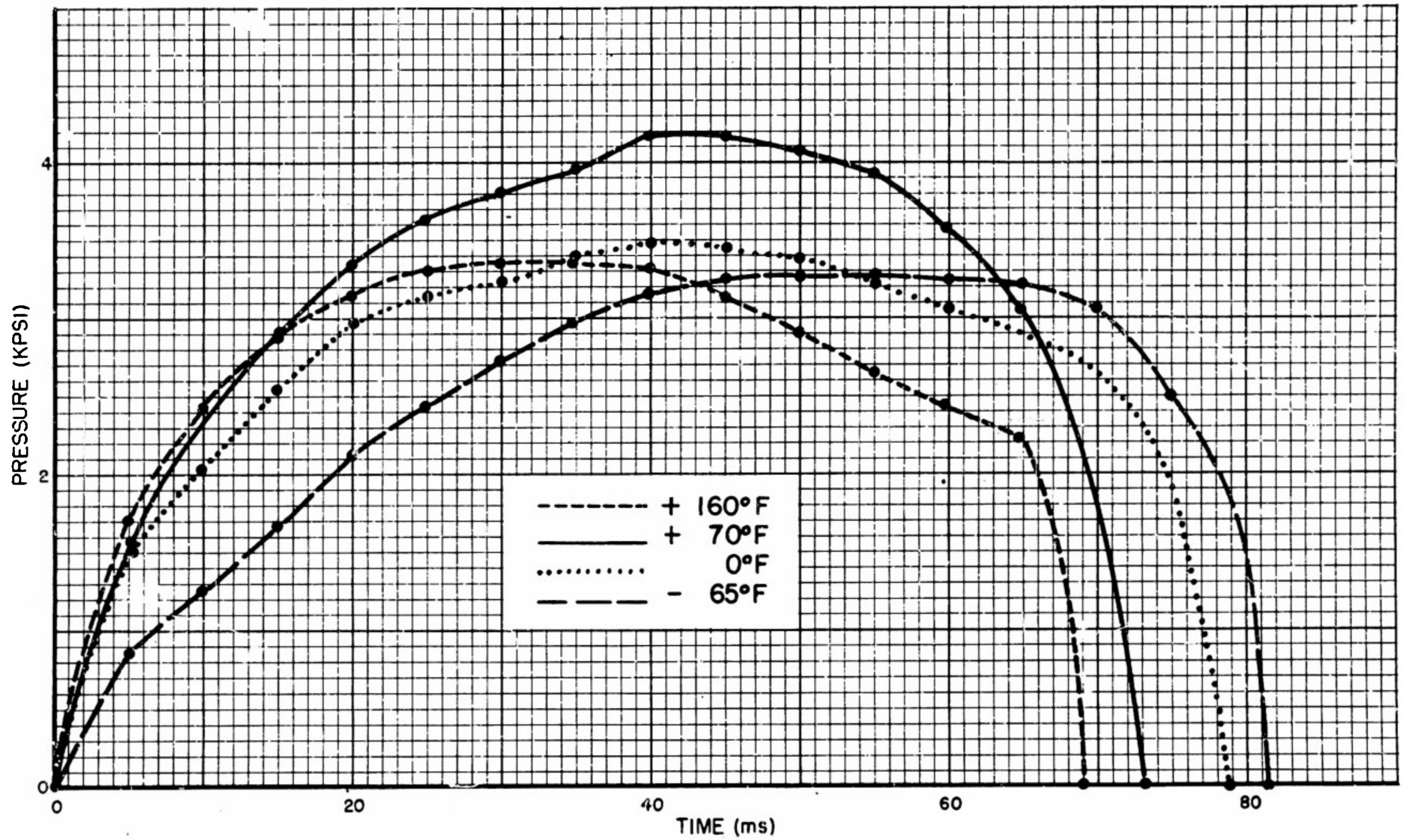
NOTE: A —— MEANS NO VALUE OBTAINABLE. FIGURES MARKED * MEAN THAT READING TAKEN FROM LOW-GAIN TRACE. ALL TIMES IN MILLISECONDS

TABULATION OF DATA

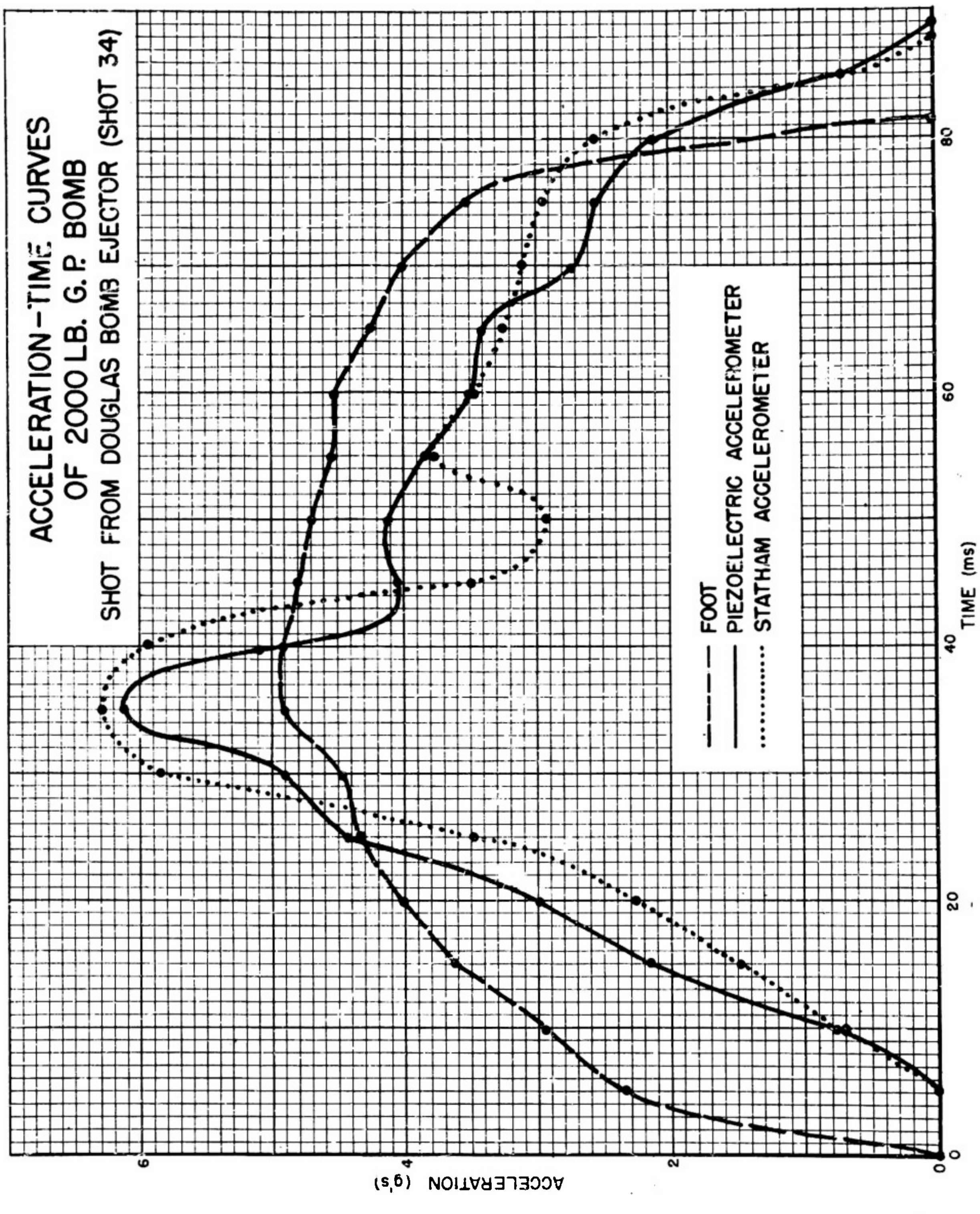
DOUGLAS BOMB EJECTOR DATA — CALCULATIONS

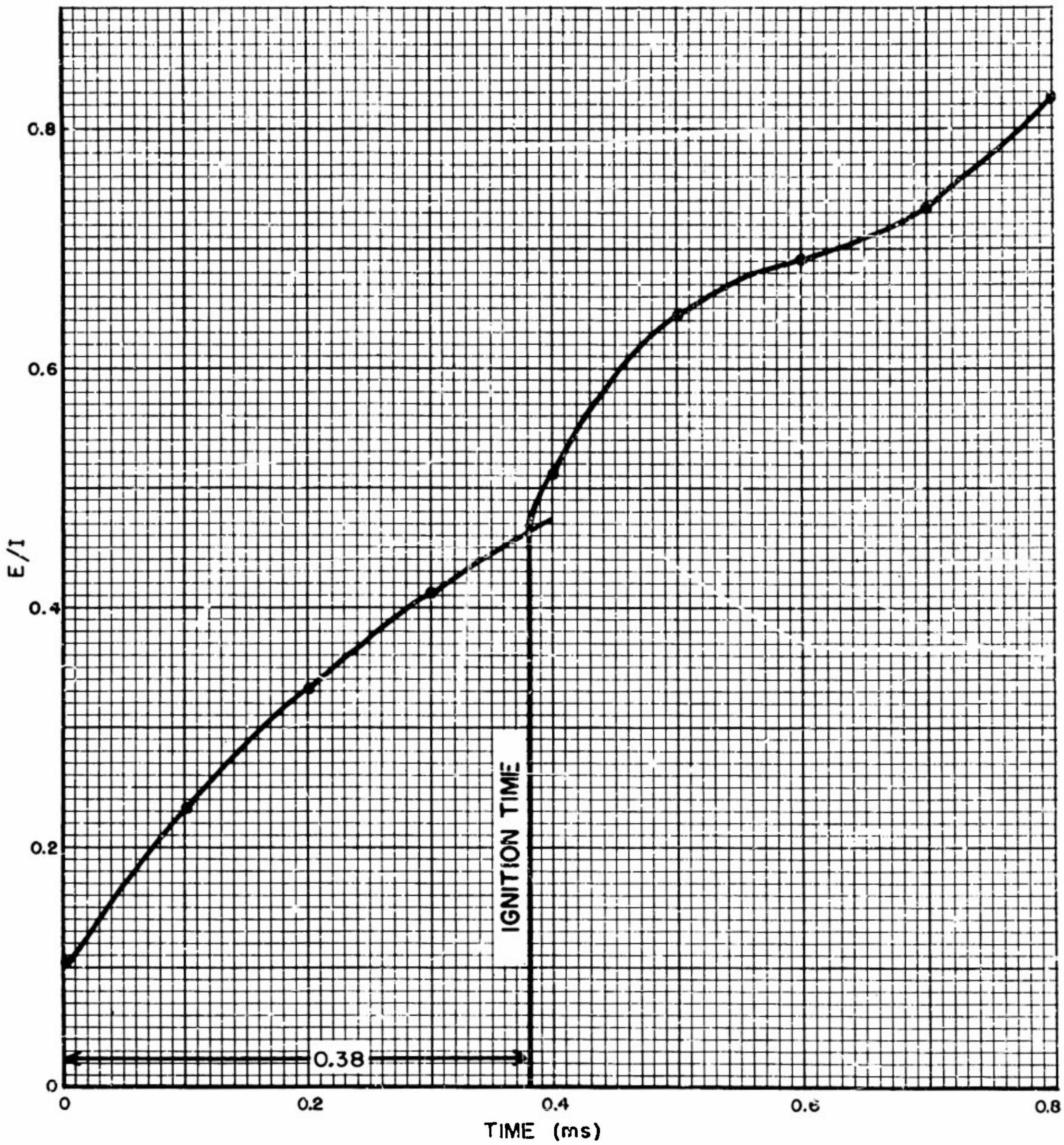
	Type of Measurement*	Cartridge Retainer and Treatment of Cartridge	Averages and Standard Deviations* for +160° Mean	+160° S.D.	+70° Mean	+70° S.D.	0° Mean	0° S.D.	-65° Mean	-65° S.D.	Total Mean	Total S.D.
1-	Time of Beginning of Pressure - Measured from Application of Current.	A. Vibrated Cartridge in Ret. B.	23.75	27.2408	4.27	3.7091	2.05	0.4821	4.84	4.0135		
		B. Non-Vib. Cart. in Ret. B.			2.02	0.7436	2.36	1.2744				
		C. All in Cart. Ret. C.			3.09	2.3079	2.25	0.7064				
		Total	23.75	27.2408	2.87	2.3266	2.23	0.8914	4.84	4.0135	5.61	11.7280
2-	Time of Hook Opening - Measured from Pressure Rise.	A. Vibrated in Cart. Ret. B.	3.77	1.7509	3.57	0.4665	3.65	0.9516	3.58	0.4924		
		B. Non-Vib. in Cart. Ret. B.			3.48	1.1507	3.32	0.6285				
		C. All in Cart. Ret. C.			3.36	0.8489	4.05	0.9852				
		Total	3.77	1.7509	3.62	0.9972	3.80	0.8130	3.58	0.4924	3.710	1.0319
3-	Time of Peak Pressure - Measured from Pressure Rise.	A. Vibrated in Cart. Ret. B.	33.55	6.8686	39.57	2.9688	41.05	5.7525	53.85	10.7873		
		B. Non-Vib. in Cart. Ret. B.			42.50	8.3760	37.18	2.4350				
		C. All in Cart. Ret. C.			41.19	2.3899	49.71	1.8468				
		D. All in Cart. Ret. B.	33.55	6.8686	41.45	6.9280	38.97	4.5598	53.85	10.7873		
		Total	33.55	6.8686	41.41	6.3026	41.44	6.1874	53.85	10.7873	42.42	8.4924
4-	Time of Pressure Drop to Zero - Measured from Pressure Rise.	A. Vibrated in Cart. Ret. B.	69.14	2.1644	76.21	3.9195	75.93	3.4895	81.53	4.1828		
		B. Non-Vib. in Cart. Ret. B.			68.27	3.1682	75.53	1.8728				
		C. All in Cart. Ret. C.			80.32	2.2816	86.34	3.6581				
		D. All in Cart. Ret. B.	69.14	2.1644	70.75	5.0263	75.72	2.4031	81.53	4.1828		
		Total	69.14	2.1644	72.26	5.8714	78.22	5.5143	81.53	4.1828	75.41	6.[illegible]192
5-	Time to Acceleration Rise Measured from Application of Current.	A. Vibrated in Cart. Ret. B.	27.09	26.4422	5.34	3.5555	4.34	1.3456	5.98	3.9768		
		B. Non-Vib. in Cart. Ret. B.			3.79	0.8595	4.93	1.7439				
		C. All in Cart. Ret. C.			6.45	4.0871	4.48	1.4988				
		Total	27.09	26.4422	4.60	2.4651	4.62	1.5284	5.98	3.9768	7.08	10.6413
6-	Time of Peak Acceleration Measured from Acceleration Rise.	A. Vibrated in Cart. Ret. B.	25.22	4.7654	32.45	3.2812	30.19	5.2365	40.73	8.7661		
		B. Non-Vib. in Cart. Ret. B.			27.83	1.8851	29.81	3.1853				
		C. All in C. Ret. C.			34.16	5.2892	31.40	8.3086				
		D. All in Cart. Ret. B.	25.22	4.7654	29.63	3.3545	29.98	4.1356	40.73	8.7661		
		Total	25.22	4.7654	30.08	3.6726	30.29	5.1418	40.73	8.7661	30.76	1.9591
7-	Time of Acceleration Fall to Zero - Measured from Acceleration Rise	A. Vibrated in Cart. Ret. B.	73.66	2.9776	81.52	4.7875	77.92	7.1651	86.20	7.1665		
		B. Non-Vib. in Cart. Ret. B.			70.73	4.2333	81.34	2.4711				
		C. All in Cart. Ret. C.			85.28	9.2348	87.81	4.9723				
		Total	73.66	2.9776	76.23	7.6257	81.93	6.6485	86.20	7.1665	79.69	7.6356
8-	Pressure at which Hooks Opened - in lbs./in.²	Total	1354	357.1	1025	562.1	1064	494.5	506	479.0	1002	544.6
9-	Peak Pressure in lbs/in.²	A. Vibrated in Cart. Ret. B.	3418	423.5	4007	671.9	3738	750.6	3457	689.7		
		B. Non-Vib. in Cart. Ret. B.			4635	435.2	3784	401.1				
		C. All of Cart. Ret. C			5658	603.1	5258	447.2				
		D. All in Cart. Ret. B	3418	423.5	4411	544.1	3763	561.9	3457	689.7		
		Total	3418	423.5	4278	648.0	3644	576.1	3457	689.7	3843	689.7
10-	Peak Pressure Values Calculated into g's.	A. Vibrated Ca[illegible] in Cart. R. B	4.20	0.5246	4.91	0.8062	4.61	0.9443	4.26	0.8701		
		B. Non-Vib. in Cart. Ret. B.			5.72	0.5394	4.65	0.5156				
		C. All in Cart. Ret. C.			4.52	0.7553	4.01	0.6292				
		Total	4.20	0.5246	5.27	0.8008	4.48	0.7280	4.26	0.8701	4.73	0.8600
11-	Peak Acceleration Values - in g's.	A. Vibrated in Cart. Ret. B.	7.23	1.7336	6.04	1.2163	5.55	1.7037	5.82	1.2936		
		B. Non-Vib. in Cart. Ret. B.			8.35	1.5044	7.08	1.2706				
		C. All in Cart. Ret. C.			5.52	0.6152	4.73	0.7234				
		Total	9.23	1.7336	7.22	1.7819	6.03	1.6344	5.82	1.2936	6.71	1.9181

* Note: All times measured in milliseconds. The standard deviation indicates the variation in the data -



AVERAGE PRESSURE-TIME CURVES
(2000 LB. G.P. BOMB)


ACCELERATION-TIME CURVES
OF 2000 LB. G.P. BOMB
SHOT FROM DOUGLAS BOMB EJECTOR (SHOT 34)
FOOT
PIEZOELECTRIC ACCELEROMETER
STATHAM ACCELEROMETER
ACCELERATION (g's)
TIME (ms)
0
2
4
6
0
20
40
60
80



PLOT OF E/I TO DETERMINE IGNITION TIME

SHOT 1
RECORD 65
BRIDGE-WIRE BREAK = 0.953 ms